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(54) Title: ACTIVE ANTENNA ARRAY CONFIGURATION AND CONTROL FOR CELLULAR COMMUNICATION SYSTEMS

(57) Abstract: Various antenna arrangements are provided with active transmit and receive antenna elements for transmitting and receiving signals within a cellular communication system. Also presented are specific base station antenna systems and methods, and portions thereof, which improve and control specific characteristics and features of antenna systems including antenna beam patterns. In addition, a method for the optimization of a cellular communications network is provided which exploits reverse-link, forward-link, and pilot signal information to optimize network operations.

ACTIVE ANTENNA ARRAY CONFIGURATION AND CONTROL FOR CELLULAR COMMUNICATION SYSTEMS

BACKGROUND OF THE INVENTION

1.   Reservation of Copyright

The disclosure of this patent document contains material which is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent document or the patent disclosure, as it appears in the U.S. Patent and Trademark Office patent files or records, but otherwise reserves all copyright rights whatsoever.

2.   Related Application Data

The present application is related to the disclosures provided in the U.S. application entitled "Scalable Cellular Communication System" filed (Attorney Docket No. 259817/81746) on even date herewith in the names of Joseph Shapira and Gideon Argaman.

This application is a continuation-in-part of the co-pending U.S. Application No. 09/171,986, filed October 30, 1998, which was the National Stage of International Application No. PCT/IL98/00104, filed March 3, 1998, which claimed the benefit of (and accordingly, this application also claims the benefit of) each of Israeli Application Nos. 120364, filed March 3, 1997, 120706, filed April 20, 1997, and 121201, filed June 30, 1997.

This application is also a continuation-in-part of the co-pending PCT International

Application No. PCT/IL98/00103, filed March 3, 1998, which claimed the benefit of (and

accordingly, this application also claims the benefit of) each of Israeli Application Nos.

120364, filed March 3, 1997, 120706, filed April 20, 1997, and 121201, filed June 30,

5   1997.

The contents of each and every one of the aforementioned applications are hereby

expressly incorporated by reference herein in their entireties.

3.   **Field of the Invention**

10   This invention generally relates to the field of cellular communications. More

particularly, the present invention relates to an active antenna array configuration for

cellular communication systems.

4.   **Description of Background Information**

15   Today's cellular communication systems are subjected to ever-increasing user

demands. Current subscribers are demanding more services and better quality while

system capacities are being pushed to their limits. The challenge, therefore, is to provide

feasible and practical alternatives that increase system capacity while achieving better grades

of service.

20   Typically, for each geographic cell, cellular communication systems employ a base

station (BS) with an omni-directional antenna that provides signal coverage throughout the

cell. One way to increase the communications capacity, is to split the geographic cell into

a plurality of smaller cells (i.e., cell-splitting) by deploying additional BSs within the cell,

thereby increasing the number of frequencies that can be re-used by the system. This cell-

splitting, however, can be both cost-prohibitive and environmentally-deterred as

conventional BS equipment include antenna arrangements which are expensive and often

5   too bulky and unaesthetic for prevailing community standards.

An alternative approach to improving system capacity and maintaining service

quality is to angularly divide the geographic cells into sectors (i.e., sectorize) and deploy

BS antennae that radiate highly-directive narrow beam patterns to cover designated sectors.

The directive beam patterns can be narrow in both the azimuthal and elevation plane and,

10   by virtue of their directional gain, enable mobile stations (MSs) to communicate with the

BS at longer distances. In addition, system capacity increases as the sectorized cells are not

as susceptible to interference from adjacent cells.

The narrow beams used to form beam patterns for given coverage areas are

optimized to improve performance of the wireless network. An ideal goal is to provide

15   exceptional service quality (e.g., no dropped calls), enhanced capacity, low per-site costs

enabled by large coverage areas, and long battery service periods for MSs. There are

various methods for optimizing the antenna arrangement. For example, wireless systems

engineers have historically employed BS design rules regarding RF propagation-based

coverage in order to "balance the link." This approach involves controlling the BS antenna

20   gains and antenna heights for transmission and reception, BS transmit power levels, and

BS receive sensitivity parameters. These different parameters are selected to provide

approximately equal coverage for the MS-to-BS link (i.e., reverse link) as is provided for

the BS-to-MS link (i.e., the forward link).

A need still exists to further lower costs of deployment and operations and to

provide better coverage/capacity at lower costs. Accordingly, steps have been taken to

5   introduce new technologies, such as CDMA technologies, for example, which can operate

in environments involving high intra-system interference and yet provide exceptionally

high capacity with low transmit power levels. These new environments and technologies

require even more sophisticated network and design approaches and interference mitigation

strategies.

10   As such, there exists a need for improvements in antenna systems and arrangements

as well as systems for controlling antenna beam patterns in light of the above-identified

issues.

15   SUMMARY OF THE INVENTION

The present invention is provided to improve upon wireless communication

systems. Certain aspects of the present invention are presented which provide

improvements to antenna arrangements in cellular wireless communication systems. Such

improvements include the implementation of active transmit and receive antenna elements

20   in specific configurations for cellular applications.

Another aspect of the present invention provides specific base station antenna

systems and methods, and portions thereof, which improve and control specific

characteristics and features of antenna systems including transmit and receive beam-shaping, polarization diversity processing, directional antenna controllers, etc.

In addition, a method for the optimization of a cellular communications network is provided which exploits reverse-link, forward-link, and pilot signal information to

5   optimize the network operations.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention are

10   further described in the detailed description which follows, with reference to the drawings by way of non-limiting exemplary embodiments of the present invention, wherein like reference numerals represent similar parts of the present invention throughout the several views and wherein:

FIG. 1A is a high level diagram depicting a first type of antenna arrangement;

15   FIGS. 1B and 1C show beam patterns;

FIGS. 2A and 2B show different antenna arrangement units;

FIG. 3A shows an active radiator unit;

FIGS. 3B and 3C depicts other antenna arrangements;

FIG. 4 is a high level system diagram depicting an antenna arrangement and

20   transform matrix;

FIG. 5A is a high level diagram illustrating a BS antenna system capable of shaping composite beams;

FIG. 5B is a high level diagram illustrating a shaped composite beam;

FIG. 6A is a high level diagram illustrating a receive portion of a BS antenna system;

FIG. 6B is a high level diagram illustrating a transmit portion of a BS antenna system;

FIG. 7A is a high level diagram illustrating a receive portion of a BS antenna system;

FIG. 7B is a high level diagram illustrating a transmit portion of a BS antenna system;

FIG. 8 is a high level diagram depicting a BS antenna system;

FIG. 9A is a high level diagram illustrating a receive portion of a BS antenna system;

FIG. 9B is a high level diagram illustrating a transmit portion of a BS antenna system;

FIG. 10A is a high level diagram illustrating a receive portion of a BS antenna system;

FIG. 10B is a high level diagram illustrating a transmit portion of a BS antenna system;

FIG. 11A is a high level diagram depicting a transmit portion of a BS antenna system;

FIG. 11B is a high level diagram depicting a transmit portion of a BS antenna system;

FIG. 12A is a high level diagram depicting a multi-carrier receive portion of a BS antenna system;

FIG. 12B is a high level diagram depicting a multi-carrier receive portion of a BS antenna system;

5   FIG. 13 is a high level diagram illustrating a receive portion of a multiple antenna management BS system;

FIG. 14 is a high level diagram illustrating a receive portion of a multiple antenna management BS system;

FIG. 15A is a functional block diagram of a directional transmit antenna subsystem;

10   FIG. 15B is a functional block diagram of a directional transmit antenna subsystem;

FIG. 15C is a functional block diagram of an exemplary BS system;

FIG. 15D is a functional block diagram of another exemplary BS system;

FIG. 16 is a diagram depicting overlapping cells and soft hand-off zones;

FIG. 17A is a graph of BTS received power versus load;

15   FIG. 17B is a flow chart of an optimization process; and

FIG. 18 is a diagram of plural antenna arrangements with coordinated beam shaping control and a common receive and/or transmit RF signal.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

20   FIG. 1A depicts a conventional BS antenna array 100, having an 8 x 1 (columnar) arrangement. This antenna arrangement comprises either all transmit or all receive antenna elements. Such an antenna arrangement is capable of radiating highly directional beam

patterns in either the elevation or azimuthal plane. Inputs to the array 100 are facilitated by

a corporate feed, which. interconnects the antenna elements.

FIGs. 1B, 1C illustrate different perspectives of a representative radiation beam

pattern of a columnar antenna array, such as, antenna array 100, for example. FIG. 1B

5   depicts the radiation beam pattern in the azimuthal plane while FIG. 1C depicts the pattern

in the elevation plane. As can be seen from the FIG. 1C, the beam pattern is highly

directive in the elevation plane.

FIG. 2A illustrates an active antenna array configuration for a BS. As depicted in

FIG. 2A, antenna array 200 comprises a combination of 2 active transmit antenna elements

10   205A, 205B and 2 active receive antenna elements 210A, 210B, arranged in a single

vertical (columnar) array. The 2 active transmit antenna elements 205A, 205B and 2 active

receive antenna elements 210A, 210B, are preferably printed elemental radiators having a

multi-layer configuration & sealed by an epoxy-fiberglass radome.

By incorporating separate transmit antenna elements 205A, 205B and receive

15   antenna elements 210A, 210B within a single array, the BS is capable of achieving full

transmission and reception functionality for cellular operations while eliminating the need

for independent transmission and reception antenna arrays, as depicted in FIG. 1. In doing

so, antenna array 200 achieves full BS functionality in a streamlined and compact design.

The spatial separation of the transmit 205A, 205B and receive antenna elements

20   210A, 210B within the array also avoids the intermodulation interference on the receive

portion caused by the high power transmit signals, as stated above with respect to

conventional combined-element systems. The spatial separation also provides flexibility in

BS transmission and reception optimization schemes. such as. for example. independent

gain control and beam-shaping, which is limited in combined-element systems. In

addition, the separation also obviates the need for signal discriminating hardware, such as

duplexers and complex transmit and receive filters which, in attempting to isolate and filter

5   the respective signals from combined transmit/receive antenna elements, operate in a

relatively lossy and inefficient manner. Such spatial separation also results in additional

isolation between the receive and transmit signals.

FIG. 2A further illustrates that, within the vertical arrangement, the antenna

elements are disposed in an alternating fashion such that a first transmit antenna element

10   205A is followed by a first receive antenna element 210A and a second transmit antenna

element 205B is followed by a second antenna element 210B. The interleaving of the

transmit 205A, 205B and receive antenna elements 210A, 210B within the array enables

the optimal vertical separation distance S to be established. Optimal vertical separation

distance S is the vertical distance between like antenna elements which, for a given

15   frequency, maximizes the main lobe gain of a signal while minimizing the contribution of

minor lobes. The optimal vertical separation distance S can vary. For example, in PCS, S

may be from 0.70λ to 0.95λ.

Additionally, the transmit 205A, 205B and receive antenna elements 210A, 210B

within the array antenna are configured to produce polarized radiated patterns. Artisans of

20   ordinary skill in the art will readily appreciate that polarization of a radiated pattern in a

specified direction results in the maximum gain of the pattern along the specified direction.

Because antennas in permanently-installed MSs (i.e., units hard-wired in vehicles) are

vertically polarized. the most suitable polarization for the pattern radiated by the BS transmit antenna elements 205A, 205B, is vertical polarization.

Because of multipath considerations, coupled with the relatively low transmit power of MSs, each of receive antenna elements 210A, 210B comprises a pair of

5   orthogonally polarized receive antenna elements, and is thus equipped with receive polarization diversity. Polarization diversity typically requires two antenna elements that are orthogonally polarized. The effectiveness of receive polarization diversity depends on the similarity of the radiated patterns received by the two antenna elements and on the equality of the average signal level received by the elements. For example, a hand-held

10   MS's transmit antenna is linearly polarized and the polarization is randomly distributed depending upon the position in which the MS is held. As such, antenna array 200 exploits these polarization states by configuring each of the receive antenna elements 210A, 210B to accommodate two opposing linearly-slanted polarized states (i.e., ±45° linear polarization).

15   It is to be understood that the specific arrangement of antenna array 200 may be modified to provide redundancy or otherwise enhance the attributes and characteristics of the array configuration. For example, antenna array 200 may be augmented by stacking combinations of the array to achieve antenna elements arranged in an 8 x 1, 12 x 1, or 16 x 1 array configuration.

20   FIG. 2A, therefore, illustrates a compact single-column array antenna configuration for cellular communications having full transmission and reception capabilities. The configuration enables independent transmit and receive gain control and beam-shaping,

minimizes transmit intermodulation interference. and provides receive polarization
diversity.

FIG. 2B illustrates another active antenna array configuration for a BS. As depicted
in FIG. 2B, antenna array 250 comprises a combination of 2 active transmit antenna
5   elements 255A, 255B and 2 active receive antenna elements 260A, 260B, arranged in a
single vertical (columnar) array. As stated above with respect to the first embodiment, by
virtue of spatially separating the transmit antenna elements 255A, 255B from the receive
antenna elements 260A, 260B, antenna array 250 achieves full BS transmission and
reception functionality while obviating transmit intermodulation effects on the receive
10 portion. Much like antenna array 200, antenna array 250 also provides the flexibility of
independent gain control and beam-shaping for both BS transmission and reception as well
as establishing the optimal separation distance S between like antenna elements.

Antenna array 250 also provides the additional benefit that it is configured to
provide polarization diversity for both the BS transmit antenna elements 255A, 255B and
15 the BS receive antenna elements 260A, 260B. As stated above, because of the manner in
which a handheld MS operates, the polarization of a corresponding MS receive antenna is
randomly distributed. As depicted in FIG. 2, antenna array 250 exploits these polarization
states by configuring each of the BS transmit antenna elements 255A, 255B and each of the
receive antenna elements 260A, 260B to accommodate two opposing linearly-slanted
20 polarized states (i.e., ±45° linear polarization).

It is to be understood that the specific arrangement of antenna array 250 may be
modified to provide redundancy or otherwise enhance the attributes and characteristics of

the array configuration. For example, antenna array 250 may be augmented by stacking

combinations of the array to achieve antenna elements arranged in an 8 x 1, 12 x 1, or 16 x

1 array configuration array configuration. This arrangement, therefore, provides a compact

single-column array antenna configuration for cellular communications having full

5   transmission and reception capabilities. The configuration enables independent transmit

and receive gain control and beam-shaping, minimizes transmit intermodulation

interference, and provides both transmit and receive polarization diversity.

FIG. 3A depicts a representative embodiment of an Active Radiating Unit (ARU)

300, which is described in the commonly-assigned application entitled "SCALABLE

10   CELLULAR COMMUNICATIONS SYSTEM", filed on even date herewith in the name

of Dr. Joseph Shapira and which is herein incorporated by reference. The ARU 300

comprises a modular antenna unit having a transmit path and a receive path. The transmit

path incorporates a power amplifier (PA) 302 which is electrically coupled to a transmit

band-pass filter 304. The transmit filter 304 is, in turn, electrically coupled to a transmit

15   antenna 306. The transmit antenna 306 may be configured for a variety of operations,

including, for example, vertical or dual slanted-linear polarization, as indicated above in

antenna arrays 200, 250. Similarly, the receive path implements a receive antenna 316

which is electrically coupled to a receive bandpass filter 314. The receive antenna 316 may

also be configured for a variety of operations, including, for example, vertical or dual

20   slanted-linear polarization, as indicated above in antenna arrays 200, 250. The receive

bandpass filter 314 is subsequently coupled to a low-noise amplifier (LNA) 312. The ARU

300 may also include monitoring and control sub-units as well as power conditioning sub-

units in order to provide supervisory control, management functionality, and optimal

performance. As such, the ARU 300, therefore provides transmission and reception path

portions within a single modular unit.

FIG. 3B illustrates antenna array 350, deploying a plurality of ARUs 300 in an 8 x 1

5   (columnar) arrangement. Inputs to the array 350 are facilitated by two corporate feeds,

which respectively interconnect all the transmit antenna elements and all the receive

antenna elements. As stated above with respect to ARU 300, the transmit elements may be

vertically polarized and the receive antenna elements may be linearly-slant polarized (i.e.,

±45° linear polarization). Alternatively, antenna array 350 may be configured to have

10   transmit and receive polarization diversity by configuring both the transmit antenna

elements and the receive antenna elements to have linearly-slant polarization.

FIG. 3C illustrates a third active antenna array configuration for a BS. As depicted

in FIG. 3C, antenna array 375 comprises a combination of 16 active transmit antenna

elements 385A-385P and 16 active receive antenna elements 390A-390P, arranged in a

15   multi-columnar array. As stated above with respect to the other disclosed embodiments, by

incorporating transmit antenna elements 385A-385P and receive antenna elements 390A-

390P within the array and by spatially separating the transmit antenna elements 385A-385P

from the receive antenna elements 390A-390P, antenna array 375 achieves full BS

transmission and reception functionality while obviating transmit intermodulation effects

20   on the receive portion. Antenna array 375 also provides the flexibility of independent gain

control and beam-shaping for both BS transmission and reception. Because of its unique

two-dimensional configuration, array 375 facilities the optimal and near-optimal vertical

separation distances S and horizontal separation distances S_1 between like antenna elements.

Antenna array 375 may be coupled to bear shaping circuitry to provide a plurality of narrow beam patterns. Narrower beams are more directional than their wider counterparts.

5   Such directivity arises from higher gains in predetermined directions which yields an improvement in range and makes the beam patterns less susceptible to interference. Thus, MSs, operating under the same power constraints, can communicate with the BS over longer distances.

For the reasons stated above with respect to other embodiments, the transmit

10   elements 385A-385P of antenna array 375 may be vertically polarized and the receive antenna elements 390A-390P may be linearly-slant polarized (i.e., ±45° linear polarization). It is to be noted that, similar to the previously-identified configurations, antenna array 375 may achieve transmit and receive polarization diversity by configuring both transmit antenna elements 385A-385P and receive antenna elements 390A-390P to be

15   linearly-slant polarized.

It is to be understood that the specific 8 x 4 arrangement of antenna array 375 may be modified to provide redundancy or otherwise customize the attributes and characteristics of the array configuration. For example, antenna array 375 may be augmented by stacking combinations of the array to achieve antenna elements arranged in an 16 x 4 or 8 x 8 array

20   configuration.

FIG. 4 illustrates a generic implementation of a BS antenna system 400 comprising a multi-columnar antenna arrangement 410 coupled to a transform matrix 420. As

illustrated in FIG. 4. the antenna arrangement 410 and the transform matrix 420 are configured for either transmit or receive BS operations. The transform matrix 420 comprises a plurality of beam ports on a beam-plane side of the matrix 420 and a plurality of antenna ports of the antenna-plane side of the matrix. Each column array of the multi-

5   columnar array arrangement 410 is coupled through the matrix 420 to the beam ports. During BS system 400 transmission, this configuration enables the transform matrix 420 to receive signals, which include relative amplitude and phase information, from the beam-plane ports. Based on this information, the matrix 420 transforms the beam-plane signals into signals appropriate for the radiating antenna elements and delivers·such signals to all

10   the antenna ports. The antenna elements within the columns of multi-column array 410, then radiate a narrow beam patterns in different directions in accordance with the transformed signals. Conversely, during BS system 400 reception, the transform matrix 420 receives signals from the antenna-plane ports and transforms them into signals appropriate for processing. As such, the illustrated system 400 forms a plurality of narrow

15   beam patterns that span different angular directions for a given axis. In the illustration, each beam port is associated with one of those beam patterns.

FIG. 5A illustrates a BS antenna system 500 comprising a multi-columnar antenna arrangement 510 coupled to a transform matrix 520. As illustrated in FIG. 5A, each of the beam ports on the beam-plane side of the transform matrix 520 is coupled to an amplitude

20   or gain adjusting element 530 and a phase adjusting element 540. Elements 530, 540 allow for amplitude/gain and phase adjustments to be made in order to control the shape of the antenna beam patterns, as indicated in FIG. 5B.

FIG. 5B illustrates a typical composite beam pattern radiated by a BS system, such as BS antenna system 500 depicted in FIG. 5A. The transform matrix 520 supplies signals to the antenna ports which enables the antenna elements to form four individual beams. The aggregate effect of these individual beams is the envelope composite beam, as indicated in FIG. 5B. As stated above, amplitude/gain adjusting elements 530 and phase adjusting elements 540 make it possible to control the shape of the antenna beam patterns. The amplitude level at which the individual beams (i.e., sub-beams) intersect is called the cross-over level. The position of the cross-over level depends, at least in part, on the optimal separation distance of the antenna elements contained in the antenna array 510.

FIG. 6A illustrates a receive portion of a BS antenna system 600 comprising a multi-columnar receive antenna arrangement 610 coupled to a receive transform matrix 620. Each of the beam ports on the beam-plane side of the receive transform matrix 620 is coupled to an amplitude/gain adjusting element 630 and a phase adjusting element 640. Similarly, FIG. 6B depicts a transmit portion of a BS antenna system 650 comprising a multi-columnar transmit antenna arrangement 660 coupled to a transmit transform matrix 670. Each of the beam ports on the beam-plane side of the transmit transform matrix 670 is coupled to the amplitude/gain adjusting element 680 and a phase adjusting element 690.

FIG. 7A depicts a receive portion of a BS antenna system 700 comprising a receive transform matrix 720 with matching phase center capability. This capability enables the transform matrix to generate beam patterns with identical phase centers. As such, phase adjustment elements external to the transform matrix 720 are not provided. Amplitude/gain adjustments are accomplished through the amplitude/gain adjusting

elements 730 which are coupled to the beam ports. Similarly, FIG. 7B depicts a representative embodiment for the transmit portion of a BS antenna system 750, comprising an antenna arrangement a Tx transform matrix with matched phase centers, amplitude/gain adjusters 780, and a splitter.

5   FIG. 8 illustrates a BS antenna system 800 comprising a multi-columnar antenna arrangement 810 coupled to a transmit transform matrix 820 and receive transform matrices 822, 824, respectively. The multi-columnar antenna arrangement 810 includes one or more transmit-receive antenna sets; each set includes two receive antenna elements and a single transmit antenna element. The illustrated arrangement is used to achieve

10   polarization diversity on the receive portion of the system 800. It is to be noted that other antenna arrangements may be provided for, such as two transmit and two receive antenna elements per transmit-receive antenna set, or multiples thereof, for example, to achieve diversity on both the transmit and receive portions. Each of the transmit and receive antenna elements within the columns of the array arrangement 810 are associated with the

15   antenna ports corresponding to the respective transmit 820 and receive matrices 822, 824. Each polarization state for the receive portion is routed to its own dedicated transform matrix 822, 824, having its own separate host of amplitude/gain adjustments. As such, each polarization state can be controlled separately for each radiated beam pattern.

        FIG. 9A illustrates a receive portion of a BS antenna system 900 comprising a

20   multi-columnar antenna arrangement 910 coupled to a receive transform matrix 920. The multi-columnar arrangement 910 includes a delay unit 911 between two polarization-diverse receive antenna elements within each column. The delay unit, as implemented,

provides a delay between the two receive polarization states. These two states are then transformed by a single receive transform matrix 920 with amplitude/gain adjustment elements on the beam port side. By virtue of the delay between polarization states, this configuration allows the BS to distinguish between the Rx signals received over receive

5   antennas of different polarizations, without requiring separate antenna ports and Rx transform matrices for differently polarized receive antenna elements. FIG. 9B illustrates a transmit portion of a BS antenna system 950, which is the transmit analog of system 900, and which comprises antenna arrangements 960, delay elements 965, a transmit transform matrix 970, and a splitter.

10   FIG. 10A illustrates a receive portion of BS antenna system 1000 comprising a multi-columnar antenna arrangement 1010 coupled to receive transform matrices 1020, 1022. The multi-columnar arrangement 1010 includes a set of polarization-diverse receive antenna element pairs within each column, and separately polarized .receive antenna elements within each set are fed to each respective transform matrices 1020, 1022. On the

15   beam ports, two sets of amplitude/gain attenuation adjustments 1030, 1032 are incorporated, and the beam port signals are respectively combined to form two polarized receive beam patterns. A delay 1040 is introduced into one of the polarized beam patterns, the result of which is combined with the other polarized beam pattern to form a single composite beam pattern. Such a configuration provides an additional degree of controlling

20   polarization diversity in a multi-beam environment. It is to be noted that, generally, the configurations depicted by FIGs. 9A and 10A would generate dissimilar antenna patterns. However, both configurations could be adjusted to generate identical beam patterns. FIG.

10B illustrates a transmit portion of a BS antenna system 1050, which is the transmit

analog of system 1000, and which comprises antenna arrangements 1060, transform

matrices 1070, 1072, amplitude adjusters 1080, 1082, splitters, and time delay element

1090.

5   FIG. 11A illustrates a transmit portion of a BS antenna system 1100 comprising a

multi-columnar antenna arrangement 1110 coupled to a transmit transform matrix 1120.

Within each column of the multi-columnar antenna arrangement 1110, there exists an

amplitude/gain adjustment element 1112 and phase adjustment element 1114 on a set of

polarized transmit antenna elements and an amplitude/gain adjustment element 1116 on

10   another set of polarized transmit antenna elements. These adjustments enable the variance

of certain characteristics, based on the polarization of the transmit beam patterns. These

two polarization states are then transformed by a single transmit transform matrix 1120.

As such, this configuration affords two degrees of control by controlling the beam pattern

on a column basis as well as controlling beam patterns on a sector basis (i.e., angular

15 . sectorized portion of a cell).

FIG. 11B illustrates a transmit portion of a BS antenna system 1150 comprising a

multi-columnar antenna arrangement 1160 coupled to transmit transform matrices 1170,

1172. At each antenna port, a transmit signal is split to create two polarized signals. One

polarized signal is amplitude/gain and phase adjusted 1190 while the other polarized signal

20   is amplitude/gain adjusted 1192. Each respective adjusted polarized signal is then

respectively split again and subsequently amplitude/gain adjusted 1180, 1182, before being

applied to separate transform matrices 1170, 1172. The transform matrices 1170, 1172

then transform these signals and supply them to the multi-columnar antenna arrangement 1160 which includes pairs of polarization-diverse transmit antenna elements within each column. Such a configuration enables BS transmit antenna system 1150 to achieve polarization matching while affording two degrees of control, namely adjustments 1190,

5   1192 to match the polarization of MSs and adjustments to optimize beam patterns 1180, 1182.

FIG. 12A depicts a receive portion of BS antenna system 1200 configured for multi-frequency allocation (i.e., multi-carrier) operation. The BS receive system 1200 comprises a multi-columnar antenna arrangement 1210 coupled to a receive transform

10   matrix 1220. The respective receive signals appearing at each of the beam ports of the receive transform matrix 1220 are divided into their carrier frequency components. This is accomplished by devices 1232, 1234, 1236, 1238 which split each beam port signal into separate frequency branches, each branch corresponding to a respective carrier frequency. For example, in FIG. 12 there exists three carrier frequencies, fc_1, fc_2, and fc_3. Each

15   frequency branch for each of the beam port signals is then amplitude/gain adjusted and combined. The combined signal is then routed to a channel filter 1240, 1242, 1244 tuned to the respective carrier frequency. This configuration, therefore, provides the capability of controlling the beam pattern for each carrier frequency utilizing a single a multi-columnar antenna arrangement 1910. Moreover, as indicated by FIG. 12B, this configuration may

20   also be implemented for a transmit portion of BS antenna system 1250, arranged for multi-frequency allocation operation.

FIG. 13 illustrates a receive portion of a BS multiple antenna system 1300 comprising a plurality of multi-columnar antenna arrangements 1310, 1312, 1314, each being coupled to a respective transform matrix 1320, 1322, 1324. The beam ports of the transform matrices 1320, 1322, 1324 are coupled to beam port branches which may include

5   adjusting elements, to effect amplitude/gain and phase adjustments, as well as modulators, to apply amplitude, phase, or polarization modulation to the beam port signals. The beam port branches are then coupled to a channelized panel device 1350, wherein each beam port signal corresponding to a sub-beam of a composite beam covering a specific sector portion of a cell is associated with a channel slot on the panel device. The channelized panel

10   device 1350 is configured so that beam port signals comprising a composite beam for a cell sector occupy contiguous channel slots. As such, this configuration provides the capability of redistributing any number of sub-beam patterns from one sector to another sector, by virtue of "patching" beam port signal branches into channel slots corresponding to a desired cell sector. It is to be appreciated that the actual "patching" of one sub-beam

15   pattern from one sector to another may be achieved by manually positioning cables on the channelized panel device 1350. Alternatively, the panel device 1350 itself may be a switching device capable of patching sub-beam patterns into different sectors without manual positioning.

FIG. 14 illustrates a receive portion of a BS multiple antenna system 1400

20   comprising a plurality of multi-columnar antenna arrangements 1410, 1412, 1414, each being coupled to a respective transform matrix 1420, 1422, 1424. The beam ports of the transform matrices 1420, 1422, 1424 are coupled to beam port branches, which include

amplitude/gain elements to adjust the amplitude of the beam port signals. The beam port

branches are then supplied to a switch mechanism 1450, which is capable of redistributing

any number of sub-beam patterns from one sector to another sector. The switch

mechanism 1450 may be configured so that all the beam port signals having identical phase

5   centers and generating sub-beam patterns to form a sector composite beam pattern, are

grouped together. Furthermore, each of the beam port signal groupings is delayed by a

predetermined amount that is unique to each grouping, such that a relative delay exists

between adjacent sub-beam patterns not sharing identical phase centers (i.e., adjacent sub-

beam patterns that are on opposite sides of a sector boundary). Such a configuration

10   provides beam pattern diversity by uncorrelating the sub-beam patterns for each sector and

minimizes interference between sub-beams on opposite sides of sector boundaries.

        FIG. 15A illustrates a system-level functional block diagram of a directional transmit

antenna subsystem 1500A. Fig. 15B illustrates a system-level functional block diagram of a

directional receive antenna subsystem 1500B. The directional transmit and receive antenna

·15   subsystems 1500, 1500B may be co-located at a BS to form a combined directional antenna

subsystem. Transmit beam shaping portion 1502A includes an input for receiving transmit

RF signals 1504A. These RF signals 1504A include information regarding transmission

channel slots, which are used to transmit information to be received by MSs.

        The antenna arrangement 1506A, as illustrated in FIG. 15A, comprises a plurality of

20   antenna arrays coupled to respective output antenna ports 1508A of transmit beam shaping

portion 1502A. While the specific embodiment illustrated in FIG. 15A provides a number of

columns which equals the number of antenna ports 1508A, this does not preclude other

configurations in which the relationship of antenna ports to arrays is not 1-to-1. It is to be

noted that the specific antenna arrangements and antenna element configurations may be

designed in any manner consistent with the various embodiments disclosed in this

application.

5   A number of parameters pertaining to individual beam patterns or sets of beam

patterns may be processed by transmit beam shaping portion 1502A. As illustrated in FIG.

15A those parameters comprise time delay 1510A, amplitude 1511A, phase 1512A,

amplitude modulation 1513A, phase modulation 1514A, and gain 1515A. More specifically,

one or more of these parameters may be set or adjusted. For example, the time delay of a

10   specific beam pattern may be adjusted or set to a specific value. In addition, the time delay

may be set to a given value, or adjusted, in a manner that affects a set of beams processed by

transmit beam shaping portion 1502A. That set may comprise the complete set of beam

patterns or a subset of those beam patterns. Other parameters, such as amplitude and phase,

for example, may similarly be set or adjusted on a per beam or a per beam set basis. The

15   amplitude and phase modulation parameters can be defined and applied to individual beams

or to a set of beams, for example, to achieve a modulation of relative amplitudes among the

beams in that set or to effect a modulation of the relative phase among beams within a set.

Similar parameters may be individual set and/or adjusted on the antenna side, i.e., within

antenna arrangement 1506A. The parameters may be set and/or adjusted with respect to

20   individual antenna elements, sets of those elements, or entire antenna element columns. In

the illustrated embodiment, those parameters include time delay 1516A, amplitude 1517A,

phase 1518A. All, a subset, or different parameters may be made settable or adjustable within the antenna arrangement.

Specific circuits (some of which are set forth below) may be utilized to implement one or more of the parameter settings or adjustments referred to in Fig. 15A. For example,

5   transmit beam shaping portion 1502A may be implemented with known circuit components, including a transform matrix, such as the Butler Transform Matrix.

The antenna elements may be implemented with the use of antenna radiator units (ARUs) as disclosed in the related Shapira application filed on even date herewith and as briefly described above (FIG. 3A). ARUs may comprise adjustable circuit elements which

10   are both monitored and controlled by a monitor and control portion provided within the ARU. As shown in FIG. 15C, a communication mechanism 1541 may be provided between beam shaping portion 1502A and a directional antenna subsystem controller 1522 and the monitor and control portions provided within the ARUs. Accordingly, a specific instruction can be communicated to adjust or set a given circuit element within the ARU. That circuit

15   element may comprise, for example, a time delay element, an amplitude adjustment element (e.g., a given amplifier in a given transmit or receive path), or a phase adjusting element. Accordingly, in order to adjust the amplitude of a given set of beams, an amplifier on the transmit or receive path, as appropriate, may be adjusted via the monitor and control portion of the ARU. This can be done instead of or in addition to adjusting the amplitude of a given

20   beam by the amplitude setting part 1511A of beam shaping portion 1502A.

FIG. 15B depicts a receive directional antenna subsystem 1500B, which comprises a receive beam shaping portion 1502B, and a receive antenna arrangement 1506B. Receive

directional antenna subsystem 1500B is the functional inverse of transmit directional antenna

subsystem 1500A. As such, a set of antenna ports are coupled between receive beam shaping

portion 1502B and receive antenna arrangement 1506B. The received RF signals are

subsequently supplied to output 1504B.

5   FIG. 15C provides a block diagram of an exemplary BS system 1520. The illustrated

system comprises a directional antenna subsystem controller 1522 coupled to a beam shaping

portion 1524, which is in turn coupled to an antenna array 1526. The beam shaping portion

1524 comprises two sets of receive antenna ports 1528, 1530 which correspond to two sets of

receive elements (e.g., main receive and diversity receive) provided within antenna array

10   1526. Similarly, two sets of transmit antenna ports 1532, 1533 are coupled to two sets of

transmit elements (e.g., main receive and diversity receive) within antenna array 1526. The

beam shaping portion 1524 also includes two sets of receive beam ports 1534, 1536 and two

sets of transmit beam ports 1538, 1539. The beam ports enable the coupling of BTS 1544 to

beam shaping portion 1524. While the connections among antenna array 1526, beam shaping

15   subsystem 1524 and BTS 1544 are shown as comprising certain sets of ports, any suitable

connections could be provided which facilitate the transfer of Rx and Tx signals.

Directional antenna subsystem controller 1522 may be further coupled to an external

computer 1540, a network management system 1542, and a BTS 1544. A mechanism 1545

may be provided for allowing communication directly between network management system

20   1542 and BTS 1544. Network management system 1542 may also comprise an interface for

receiving information from other BTSs. By way of example, antenna array 1526 may

comprise a combination of columnar arrays as illustrated in Fig. 1. Thus, each main receive

antenna element and diversity receive antenna element may be linearly slant-polarized and each main transmit antenna element and diversity transmit antenna element may be vertically polarized, as shown in FIG. 2A. Alternatively, all antenna elements may be linearly slant-polarized, as indicated in FIG. 2B.

5   FIG. 15D illustrates an antenna subsystem 1548, which demonstrates a variation on the system architecture illustrated in FIG. 15C. In the embodiment illustrated in Fig. 4D, an antenna arrangement 1526 is coupled to a beam shaping portion 1524 while other elements of the exemplary BS system are not shown in FIG. 15D (for the sake of simplification). However, an additional receive beam power monitoring mechanism 1550 may be provided

10   which functionally monitors the power of the receive beam at each beam port of beam shaping portion 1524. These beam ports may be monitored for this purpose at any appropriate location that is indicative of the receive beam power for those respective beams. For example, a mechanism may be provided within beam shaping portion 1524 which simply provides a coupling to the various beam ports on the receive side to a power measurement

15   mechanism, and generates digital values that are stored in respective registers corresponding to the respective beam ports.

Antenna array 1526 may comprise an array that forms N beams, and may be further provided with monitor and control portions, for example, as is described in the aforementioned related patent application. In addition, a monitoring and control portion may

20   be provided as part of beam shaping portion 1524. Directional antenna subsystem controller 1522 may comprise an IDU as disclosed in the above-identified related application, and it may be further provided with a monitoring and control portion as forms part of the IDU.

Network management system 442 comprises a network information database. BTS 1544

comprises sub-portions which include a transmit section, a main receive section, a diversity

receive section, and an interface to network management system 442.

As indicated in FIG. 15C, the receive antenna elements may comprise pairs of

orthogonally polarized receive antenna elements. The elements within each such pair may be

independently controlled (i.e., the antenna gain associated with each of those elements may

be independently controlled).   In addition to independently controlling the differently

polarized receive elements, the transmit elements, which may be vertically or orthogonally

polarized, may also be independently controlled.

FIG. 16 illustrates a set of cells, A, B. and C, which form part of a coverage area

for a given cellular network. This diagram is provided for reference purposes to facilitate

the following discussion regarding optimization. Each of the three cells depicted in FIG.

16 is divided into 3 sectors. More specifically, each of the cells has its own BS, which

5   comprises an antenna arrangement for radiating antenna transmit and receive beam

patterns generally corresponding to the shapes shown in FIG. 16. Those beam patterns

overlap each other so as to form the soft handoff zones SH1, SH2, SH3, and SH4, as

depicted in FIG. 16.

Certain nework optimization features will now be described, including a

10   description of an optimization algorithm illustrated in Figs. 17A-17B. These features

may be used together, or subsets of them may be used to improve (i.e., to optimize)

various aspects of a cellular communication network. The algorithm illustrated in Figs.

17A-17B provides a specific implementation of a process which may be performed by

the directional antenna subsystem controller 1522 shown in FIG. 15C or, alternatively, by

15   the transmit and receive beam shaping portions 1502A, 1502B shown in FIGs. 15A and

4B. The illustrated optimization algorithm optimizes the beam patterns formed by the

antenna arrangement for a given coverage area. As described below, the specific

embodiment is capable of performing the optimization on a cell-by-cell basis or for a

certain group of cells in a localized geographic area.

20   Many aspects of a cellular communication network may be optimized. On a

larger scale, optimization may involve a minimum frame error rate (FER) on both the

forward and reverse links. Another goal is to minimize the number of dropped calls and

a the number of calls which are not received by a given MS. The capacity of the network

28

will be maximized both from a local standpoint (e.g., on a sector-by-sector basis) and overall (i.e., throughout the entire cell or throughout a coverage area including a plurality of cells). In addition, optimization may provide for a minimal EIRP so that a substantial amount of energy will not be radiated (e.g., for regulatory and safety reasons). Moreover,

5   minimal EIRP results in the saving of power and assets. For example, systems radiating less power require less expensive components. Furthermore, the MS device power required for quality communications may be minimized. This will allow the MSs to be more compact and less expensive, while promoting longer battery life and creating less of a radiation hazard.

10   The optimization features presented herein may be used with existing systems and cellular technologies and with existing assets. In other words, by providing such features together with existing standards and cellular technologies, their benefits may be realized without substantial and costly changes to the cellular infrastructure.

Various aspects of the optimization features disclosed herein may involve known

15   techniques or concepts, some of which are disclosed in the following references: US Patent No. 5,499,395 (Doi) entitled "Cellular Mobile Communications System Having Apparatus for Changing Boundaries of Cells According to Traffic Conditions;" US Patent No. 5,861,844 (Gilmore) entitled " Method and Apparatus for Providing Redundant Coverage within a Cellular Communications System;" A. Jalali: On Cell Breathing in

20   CDMA Networks; Charles Wheatley: Trading Coverage for Capacity in Cellular Systems: a System Perspective, Microwave Journal, July 1995; J. Shapira: Microcell Engineering; and J. Shapira: The forward Link in CDMA IS95 – Did we forget

Something?, URSI Workshop, June 5, 1997. The content of each and every one of these references is hereby incorporated by references in their entireties.

Reverse Link

A number of parameters and factors will affect capacity and performance over the

5   reverse link. Those include path loss issues, which relate to the ratio E_b/I_0. This ratio is a function of the multipath environment and the steps taken to mitigate both path losses and multi-path losses. In other words, the E_b/I_0 is indicative of channel quality and comprises a frequency dependent part of path loss, while path loss in general is not dependent upon a given frequency within the band. To minimize path losses, cellular systems control the

10   power emitted by the MSs within a given coverage area (e.g., a sector or cell) over the reverse link. These power adjustments are applied equally in the radial direction (i.e., omni-directional), since MSs typically do not possess directional transmit capabilities.

There is a direct trade-off between capacity and performance: the higher the actual E_b/I_0 is, the higher the performance (lower FER) and the lower the capacity.

15   Various types of diversities may be employed to mitigate path losses.

Soft Hand-Off (SHO) provides additional space diversity, macro space diversity, and control of the other-cells interference. Larger SHO zones require a larger number of cell assets (channel cards); thus limiting the area of an SHO zone can be beneficial. Softer hand-off (between sectors of the same BS) provides additional space/antenna

20   diversity, and control of adjacent sector interference. The pathloss is correlated for collocated sector antennas and there is no macro space diversity. No extra channel cards are required.

Forward Link

30

Some of the features mentioned apply to digital systems, such as CDMA for illustrative purposes. However, the network optimization features herein may be employed in other typs of cellular networks.

A number of parameters and factors will affect capacity and performance over the

5   forward link. Those include path loss issues, which relate to the ratio E_b/I_0. The E_b/I_0 required on the forward link is different than that of the reverse link. Coherent reception reduces the requirement for a high E_b/I_0. In addition, the use of orthogonal transmission codes eliminates in-cell interference. Interference grows toward the boundaries of the cells/sectors. When there is no transmit antenna diversity (e.g., space, polarization,

10   angular) at the BS, the required E_b/I_0 is increased.

A fast, high dynamic range power control at the transmit side of the BS helps performance for the slow moving MS, e.g., in environments with a single ray, Rayleigh fading.

A loss of orthogonality due to long-delayed multipath effects will induce in-cell

15   interference.

Soft hand-off provides space micro and macrodiversity. However, it draws power from both BSs involved in the hand-off. This is only partially compensated by the BS transmit power control measures. Additional BS transmit power for the SHO zone contributes to the interference to all other MSs near or in the same SHO zone.

20   Softer Hand-off provides only micro diversity, because pathloss is fully correlated.

Network Optimization.

A number of actions can be taken to optimize the network, e.g., by enhancing the BSs. These actions may form an initial part of an overall network optimization approach.

Measures may be taken to modify the BS to enhance coverage, and thus reduce the density of BSs in the network. Such measures include using high antenna gain,

5   diversity techniques, and by providing low noise figure amplifiers in the receive paths. Various embodiments disclosed herein, e.g., the ARU, certain antenna arrangements, and certain beam shaping systems can be used to enhance coverage.

Capacity can be enhanced by using a high EIRP and incorporating diversity techniques. Link balancing helps with the achieving of the same coverage, without

10   excessive interference, and helps avoid deterioration and dropping of calls.

Soft Hand-off balancing may be employed which involves balancing the reverse links of the adjacent cells to the same point where the pilots of these cells have equal power levels as received by the BS. This helps ensure that the SHO zone is sufficiently overlapped for the pilots and the reverse links, and enables the minimization of the SHO

15   zone around the balance point. SHO balancing thus helps prevent situations where an MS loses or cannot obtain a pilot during the hand-off process.

Another measure which can be employed involves matching the cell size to the required capacity, while maintaining continuity ("cell breathing"). This means varying the sector angular span, for sector loading which is uneven among sectors in a given cell

20   and/or in a given group of cells, and varying the cell range for uneven cell loading within a given cluster of cells.

Coverage / capacity control of the reverse link

32

The environment in a cell/sector is seldom homogeneous. Certain areas may have delayed multipath components that support rake diversity, while others – e.g., a single ray Rayleigh--dominated environment do not. Certain areas are subject to more interference than other areas. Power control techniques may be employed where the power of all MS

5   transmissions within a given cell or sector is adjusted to reach the BTS with the same S/N ratio. It is to be noted that the E_b/I_0 that satisfies the FER requirement – may differ for MSs in different areas within the cell/sector. Zones that enjoy more diversities may then stretch further out, while others – shrink. Similarly – areas with excessive interference (due to adjacent cells/sectors) may need deliberate suppression of the interference by

10   reducing the gain in that direction.

The control over the shape of the receive antenna gain across the sector is therefore a very powerful tool in optimizing the coverage and increasing capacity. The gain shape that optimizes the reverse link is not necessarily the one that optimizes the forward link, because these links are different.

15   Accordingly, to best optimize a given coverage area, separate gain control may be employed in the BS for the reverse and for the forward links.

The reverse link equation is

(1)

$$q \equiv \frac{S}{N_0 W} = \frac{C/I}{1 - \left\{ (1-n)(1+f) v \, C/I \right\}} \cong \frac{C/I}{1-\eta}$$

20   And the balance between two cells is then

33

$$\frac{q_1}{q_2} = \frac{T_1}{T_2}$$

where

C/I is the signal (carrier) to noise and interference ratio,

q is the signal power normalized to thermal noise,

5   S is the power received at the BS from each user,

N_0 is the thermal noise spectral density at the receiver input,

W is the modulated carrier bandwidth,

n is the number of active calls,

f is the ratio of outside the cell/sector to within the cell/sector interference

10   v is the voice activity factor, and

T1 and T2 are the transmission losses between the MS and the respective BSs.

Beam Shaping Optimization of the Reverse Link.

A beam shaper may be incorporated on the receive (and/or the transmit) portion

15   of a BS. A beam may form and control the shapes of multiple beams which together

form a rosette covering the sector, while each individual beam covers a fraction of the

sector. A number of different exemplary embodiments of shapers are disclosed herein. A

group of rosettes may cover the whole 360 degrees of azimuth around the BS. Each beam

goes through a controlled amplifier, and then all beams belonging to a sector are

20   combined into the BTS receiver. Each beam is also monitored by a total power receiver.

34

There are advantages to providing a shaped as opposed to alternative sector antenna arrangements. One such advantage involves the extent of control over the beam shape. The slopes of the beams may be made much steeper than those of a classical sector antenna, thus reducing inter-sector overlap, interference leakage and also helping
5   to contain the softer hand-off zone. The sector coverage is shaped by controlling the gain of each of the beams. This offers a controlled overlap with the adjacent cells, and coverage shaping to accommodate changes in the environment and interference across the sector.

As described previously, with respect to Fig. 15D, e.g., each BS may be equipped
10   with a mechanism for monitoring the total power received in each beam of a given multi-beam. The total power received in a given sector can be used as a measure of the load in the sector, e.g., as shown in Fig. 17A.

$$S_T = \frac{P_{Total}}{N_0 W} = \frac{1}{1-\eta}$$
$$(2)$$

$$N = \frac{n}{1 - \frac{1}{S_T}}$$

Where N is the asymptotic load, actual setting is within .6 to .85 of N, and

15

$$\eta \doteq \frac{n}{N}$$

The relative power received in a beam is a measure of relative MS load or excessive out-of cell interference. Additional information on the MS distribution, is available at the network management center, and may be used to resolve between the two options.

In a coverage limited beam, increased gain adds range (or penetration) and reduces the MS transmit power. In an interference limited beam, gain reduction shrinks the cell boundary and reduces the interference into the cell. Additional information on the location of the MS, which may be available at the network control center, can be

5   correlated with particular MS reports on difficulties, and compensated by gain control.

Controlling the MS transmit power for the reverse link is limited by the maximum power of the MS. The corresponding control of the forward link is the transmit power setting at the BS and the power control for the individual MS.

Cluttered areas exhibiting a single ray Rayleigh fading characteristic demand very

10   high E_b/I_0 unless additional diversity measures are provided (e.g., Tx diversity). A higher gain (higher EIRP) may have to be allocated to these directions in order to even out the coverage range across the sector.

Long-delayed multipath adds interference that is not orthogonal to the signal. This interference is proportional to the total transmitted power from the BTS. The E_b/I_0 is very

15   stable as a function of the distance from the BS within the cell in such cases, up to the cell edge where the interference from other cells deteriorates it.

The forward link equation is (approximate)

$$\frac{E_b}{I_0} = \frac{W}{R_b} \bullet \frac{\beta(1+u\alpha)}{\left(\alpha + hx\frac{T_{oc}}{T_i}\right)v1}$$

(3)

20   And on the boundary it is

$$\frac{E_b}{I_0} = \frac{W}{R_b} \bullet \frac{\beta(1+u\alpha)}{(\alpha+hx)M}$$

(4)

Where •   is the fraction of the traffic out of the BTS power

alpha   is the fraction of the BTS power that is in the delayed multipath

5   v   is the voice activity factor

u   is the number of delayed multipath received in the rake

receiver

T_1 is the transmission loss from the home BTS

T_{oc} is the transmission loss from the other BTS

10   h   is the number of other BTS at the boundary

x   is the ratio of the load of the other BTSs to that of the home   BTS

l   number of traffic channels + paging

If the propagation rule around the boundary is assumed to be R^{-4} then:

For a 2 – cell boundary

$$\frac{T_i}{T_0} \cong 1 + 4\frac{\delta R}{R_0}; \frac{T_{oc}}{T_0} \cong 1 - 4\frac{\delta R}{R_0}; \frac{T_{oc}}{T_i} \cong 1 - 8\frac{\delta R}{R_0}$$

15   (5)

For a 3 cell boundary

$$\frac{T_i}{T_0} \cong 1 + 4\frac{\delta R}{R_0}; \frac{T_{oc}}{T_0} \cong 1 - 2\frac{\delta R}{R_0}; \frac{T_{oc}}{T_i} \cong 1 - 6\frac{\delta R}{R_0}$$

(6)

20   The balance of the forward links of two cells is achieved (assume • =0) at

37

$$x = \frac{T_i}{T_{or}}$$

(7)

This means that the forward link of the cell is expanding with the load.

When a sector is loaded non uniformly, a higher EIRP should be allocated to the

5   denser sub-sector, in order to minimize the total transmit power required in the sector.

However, this extends the range of the sub-sector.

Beam Shaper Optimization of the Forward Link

An initial measure for sector shaping is based on the variations of the

environment, and therefor – the required E_b/I_0, across the sector. EIRP compensation is

10   effective.

The Soft Hand-off window is determined by the pilot balancing of the adjacent

cells. By making the SHO window symmetrical around the balance of the reverse links of

these cells, benefits are achieved including balancing the reverse links, reducing the

interference and maintaining a continuous connection while roaming between the cells.

15   An objective is to bring the pilots to balance where the reverse links balance. This

requires a control on the pilot power, as a function of the loads in the home cell and in the

adjacent cells.

Pilot control can be implemented directly at the BS. However, setting of the total

BS transmit power is a more accessible control. When applying this scheme [3] the

20   forward link power control recovers the EIRP needed by each MS, while the pilot

remains as set.   The shaper offers the control of the EIRP across the inhomogeneous

sector. This applies instead of BTS power control, for tuning the pilot within each beam. The rules for the pilot tuning are derived from equations (1) and (7).

The information for the tuning is obtainable at the network management center, or otherwise estimated from the measurements of the total received power for each BTS

5   (equation (2)).

The situation known as "pilot pollution" occurs when many pilots (more than can be handled by the rake receiver of the MS) have similar E_c/I_0 in the same area. In such a case all these pilots are bound to have a low E_c/I_0, and orphan situations occur for new MSs at their access, locking to one pilot and loosing it soon after. There is no direct way

10   to identify this situation from the measurement of the total received power, though excessive power may be observed due to ill control over MSs in participating cells that are not included in the active set of pilots. Indications of this situation may be obtained:

  •   From the excessive received power

  •   From reports on access failure or dropped calls in that region. The

15   information on the MS location, expected to be available, further clarifies the situation.

  •   From reporting on the active and neighbor sets. These messages are sent by each MS to its BTS.

Once a situation is observed, the EIRP of the relevant beams overlapping in that area from different cells — is controlled in a way to shift the balance and allow for at most

20   three dominating pilots.

Fig. 17B illustrates one example embodiment of an optimization algorithm. One of the factors the optimization algorithm embodiment addresses is the mitigation of path losses and multi-path losses. Existing cellular systems minimize these factors by

controlling the power emitted by the MSs within a given coverage area (e.g., a sector or cell) over the reverse link. These power adjustments are applied equally in the radial direction (i.e., omni-directional), since MSs do not possess directional transmit capabilities. This embodiment takes additional steps beyond those of existing systems

5   and varies the shape of the beam pattern along the azimuthal direction in order to mitigate unwanted multi-path and path loss effects.

The shaping of the beam pattern may be achieved by setting up a given BS in a particular manner so that the shape of the beam pattern within predetermined coverage areas (e.g., sectors) has certain desired characteristics both over the reverse link

10   and over the forward link.

Features of the illustrated optimization algorithm embodiment include optimizing BS operations by deploying dynamic/closed-loop processes for the reverse and forward links, which will be described as follows.

Referring to Figs. 17A and 17B for the reverse link, in a first act A1702, the

15   optimization process first looks at the reverse link attributes, focusing on the load information regarding the number of subscribers/MSs that are communicating with the BS at a given time (i.e., active subscribers). This load information is obtained and categorized on a per sector basis as well as on a per beam basis when sector coverage is achieved by implementing a plurality of beam patterns. The categorization of the load

20   information into sets corresponding to several beams corresponds to the multi-beam nature of certain embodiments of the present invention, for example, as shown in FIGs. 3C-7B, and described in the text corresponding thereto. In order to obtain the load information on a per beam basis, various methods may be used, including, placing a

special sensor in a BS receiver which measures incident power on the reverse link and/or using subscriber reporting information obtained from the MSs. The load information is then related to geographic position information (e..g., one common digital representation of a geographic map).

5   The geographic map may comprise a two-dimensional representation of the geography and the location of various items with respect to that geometry, including, e.g., the cells, sectors, beam patterns, MS locations, and BS locations.

In a next act A1706, for a given cell cluster (e.g., three adjacent cells as shown in FIG. 16), a determination using MS information (e.g., information concerning the 10   locations and power levels of respective MSs within pertinent areas) is then made as to where the boundary line exists between adjacent cells or sectors. These boundary lines demarcate the hand-off boundaries, which correspond to the center of the soft hand-off zones SH1, SH2, SH3, and SH4 for the reverse link.

The BS optimization process then focuses on the forward link attributes and 15   performs certain pilot-related processes. Existing BSs transmit both traffic and pilot signal information over the forward link, and subscribing MSs measure the pilot signal strengths for all pilot signals it receives. When a new pilot signal exceeds a certain strength "threshold," the MS may be instructed to enter into a soft hand-off mode (i.e., SH1, SH2, SH3, and SH4) with that new pilot.

20   When a MS locks onto a new pilot, it enters into what is generally referred to as a "soft hand-off window." Within this window, there exist a virtual "power-distance" boundary between the adjacent cells. Generally, when the MS reaches that boundary, it will reach a point at which it can switch over to the new coverage area/cell. However,

there are instances in which the virtual power-distance boundary falls too close to one of the borders of the soft hand-off window. This can be problematic and result in the loss of the call. Such losses occur, for example, when the MS does not switch to the new pilot in time and travels into the new cell with the old pilot signal.

5   In act A1708, the illustrated optimization algorithm performs pilot signal processing on the forward link and determines pilot signal power levels with respect to positions on the geographic map. It is noted that a separate "breathing" (i.e., changing over time) map will be provided for the forward link as well as for the reverse link. These breathing maps respectively represent, the forward link and reverse link radiation

10   beam patterns pertaining to the positions and boundaries of the cells and sectors at certain times.

        In act A1710, the optimization algorithm adjusts the power levels of the pilot signals of two adjacent BSs so that they are equal/balanced at a location which coincides with the corresponding mapped boundary line identified in act A1706 using reverse link

15   information. Referring to FIG. 16, such a boundary line may be depicted on a geographic map by a line along the center of the soft hand-off zones SH1, SH2, SH3, and SH4.

        The directional antenna subsystem controller 1522 may instruct beam shaping subsystem 1524 to adjust the shape of certain individual beam patterns, which causes the pilot signal levels to be modified at certain locations near a hand-off zone area. This may

20   be controlled to force the virtual power-distance boundary to move closer to the center of the soft hand-off window.

        Referring back to act A1708, a geographic map of the varying pilot signal power levels may be obtained, for example, by using the pilot information reported by the MSs.

As positional information regarding the MSs is provided in newer systems, the locations of the MSs will be easier to identify. However, with present systems, specific positional information regarding each MS is not readily obtainable. Accordingly, an algorithm may be utilized to correlate the pilot signal information obtained by the respective MSs

5   corresponding to a particular area and to identify the location of the MS from which the pilot signal information was obtained. This facilitates the calculation of the pilot signal power level at certain locations on the map. The algorithm may identify the sector the MS is located in, obtain pilot signal power levels in adjacent sectors, correlate the pilot signal information from MSs for pilot signals that are within 5 dB from each, and

10   aggregating those pilots.

Based on the mapped pilot signal information obtained at act 1708, the soft hand-off "islands" are now identifiable based upon forward link information. In act A1710, these soft hand-off "islands" (which comprise hand-off areas determined from a forward link perspective) are compared to the boundary lines obtained from reverse link

15   information in act 1706, and the levels of the pilot signals within each of these corresponding areas (i.e., within the hand-off zones (reverse link) and within the hand-off islands (forward link)) are compared to a threshold. Those above the threshold are pilots that may be used by an MS falling within those overlapping areas to perform a hand-off.

If the number of pilots within the given overlapping area is greater than an

20   allowable number (e.g., three pilots), this might indicate the occurrence of pilot pollution which can have deleterious effects on the performance of the network in that area, e.g., resulting in dropped calls or unsuccessful attempts to access the network.

43

The algorithm will make a decision to ignore certain pilots so the the number of pilots drops to or below the allowable number. Beam rearrangement or shaping may be performed to reduce the number of pilots, i.e., to reduce the levels of the "ignored" pilots, so that for any soft hand-off zone area there is a maximum number allowed pilots (e.g.,

5   three pilots).

To adjust the power levels for the given zone area, the optimization algorithm adjusts the EIRP of those pilots. This may be achieved by adjusting the power allocated to the pilot signal (which will have an equal effect throughout the whole area served by that pilot) and/or by adjusting the antenna gain. Adjusting the power allocated to the

10   pilot signal affects the entire sector while adjusting the antenna gain may be controlled so as to affect individual beams within a given sector (i.e., beam shaping). The power allocated to a pilot signal may be changed at the BS, but requires upgrading the BS software. Alternatively, the total transmit power of the BS may be changed. In this manner, the power control of the BS recovers the power level for each traffic channel

15   while the pilot signal power remains unchanged.

Fig. 18 shows a radiation system 1800 comprising plural antenna arrangements 1802, 1806, 1808, etc. coupled to one common BTS (not shown) via a combiner and/or splitter 1816. Each of the illustrated antenna arrangements comprises a transmit and/or receive antenna elements. Some of the antenna arrangements, i.e., 1802 and 1808, are

20   coupled to receive and/or transmit beam shaping portions 1804 and 1810, respectively. Others, including antenna arrangement 1806, do not comprise a beam shaper.

The arrangements shown in Fig. 18 may be provided to accommodate different receive and/or transmit antenna coverage patterns, through one central BTS. Optional

delays 1812 and 1814 are illustrated at the BTS side of arrangements 1806 and 1808. These are provided for CDMA systems to eliminate interference patterns by decorrelating the signals with respect to those of the first arrangement 1802. Alternatively, e.g., orthogonal signals may be used for the respective different antenna arrangements for the

5   same purpose, or no such devices may be provided.

A coordinated control mechanism 1820 is illustrated. It may be embodied, e.g., within a controller 1522 as shown in Fig. 15C or within a network management center. Coordinated control mechanism 1820 provides instructions to each adaptive type of antenna arrangement (beam shaping portions 1804 and 1810 as shown) to facilitate

10   coordinated control of antenna patterns for optimizing the parts of cellular network served by those arrangements.

Such coordination may be controlled, for example, by a given optimization algorithm such as the one described above with respect to Fig. 17B. If there is a need to remove pilots from a given hand-off zone area, transmit antenna patterns serving that

15   hand-off zone area may be reallocated; for example, the same area once illuminated by arrangement 1802 may be illuminated from a different angle from a different antenna arrangement 1808.

The illustrated antenna arrangements (or others may be provided) may be connected to the common BTS in parallel or in series. They may be located close by,

20   colocated, or located remotely from each other, e.g., in order to create contiguous coverage and EIRP as needed in different areas within a given coverage area, cell, or sector.

45

While the invention has been described by way of example embodiments, it is understood that the words which have been used herein are words of description, rather than words of limitation. Changes may be made, within the purview of the appended claims, without departing from the scope and the spirit of the invention in its broader

5   aspects. Although the invention has been described herein with reference to particular structures, materials, and embodiments, it is understood that the invention is not limited to the particulars disclosed.

WHAT IS CLAIMED:

1.   An antenna array arrangement for a wireless communication network,
comprising:

a plurality of transmit active antenna elements; and

a plurality of receive active antenna elements,

wherein said transmit antenna elements and receive antenna elements are
disposed in a repeating alternating configuration such that each of said transmit antenna
elements are separated from each other by an optimal distance and each of said receive
antenna elements are separated from each other by said optimal distance.

2.   The antenna array arrangement of Claim 1, wherein said transmit antenna
elements are vertically polarized, said receive antenna elements are linearly-slant polarized,
and said transmit antenna elements and receive antenna elements are configured in a
vertical configuration.

3.   The antenna array arrangement of Claim 1, wherein said transmit antenna
elements are vertically polarized, said receive antenna elements are linearly-slant polarized,
and said transmit antenna elements and receive antenna elements are configured in a multi-
columnar configuration.

5

4.   The antenna array arrangement of Claim 1, wherein said transmit antenna elements and said receive antenna elements are linearly-slant polarized and said transmit antenna elements and receive antenna elements are configured in a vertical configuration.

5.   The antenna array arrangement of Claim 1, wherein said transmit antenna elements and said receive antenna elements are linearly-slant polarized and said transmit antenna elements and receive antenna elements are configured in a multi-columnar configuration.

5

6.   The antenna array arrangement of Claim 1, further including a plurality of active radiating units, wherein said transmit antenna elements and said receive antenna elements are incorporated within said active radiating units.

7.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of active transmit and active receive antenna elements;

a transmit transform matrix, coupled to said multi-columnar antenna arrangement, for processing signals to be transmitted by active transmit antenna elements; and

a receive transform matrix, coupled to said multi-columnar antenna arrangement, for processing signals received by active receive antenna elements,

wherein, said transmit transform matrix and said receive transform matrix

10   are separate and each one forms a plurality of narrow beam patterns that span different

angular directions in a predetermined plane.

8.   The base station antenna system of Claim 7, wherein said transmit transform

matrix and said receive transform matrix contain beam ports which are coupled to

amplitude adjusting elements, gain adjusting elements, and phase adjusting elements for

controlling a shape of said plurality of narrow beam patterns.

5

9.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing at least two active

polarization diversity antenna elements;

a delay unit coupled to one of said at least two polarization diversity antenna

10   elements for delaying a signal of said one antenna element; and

a transform matrix for forming a plurality of narrow beam patterns that span

different angular directions in a predetermined plane, said transform matrix having a

plurality of beam ports and a plurality of antenna ports.

15   10.   The method of Claim 9, wherein said two diversity polarization antenna

elements are receive antenna elements, said transform matrix processes signals received by

said active receive antenna elements, and said delayed signal of said one antenna element is

combined with a signal from the other antenna element before being processed by said transform matrix.

11.   The method of Claim 10, wherein said two polarization diversity antenna elements are transmit antenna elements, said transform matrix processes signals to be transmitted by said active transmit antenna elements.

5   12.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of first active antenna elements and a plurality of second active antenna elements, said plurality of first active antenna elements having polarization diversity from said plurality of second active antenna elements;

10   a first transform matrix, coupled to said multi-columnar antenna arrangement, for forming a plurality of narrow beam patterns that span different angular directions in a predetermined plane, said first transform matrix being associated with said plurality of first active antenna elements and having a plurality of beam ports coupled to a plurality of adjustment elements for adjusting a first plurality of beam port signals;

15   a second transform matrix, coupled to said multi-columnar antenna arrangement, for forming a plurality of narrow beam patterns that span different angular directions in a predetermined plane, said second transform matrix being associated with said plurality of second active antenna elements and having a plurality of beam ports

coupled to a plurality of adjustment elements for adjusting a second plurality of beam port

signals;

a first combiner for generating a first combined signal by combining all

signals in said first plurality of beam port signals;

5   a second combiner for generating a second combined signal by combining

all signals in said second plurality of beam port signals;

a delay unit coupled to said first combiner for delaying said first combined

signal; and

a third combiner for combining delayed first combined signal and second

10   combined signal.

13.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of first active

antenna elements and a plurality of second active antenna elements, said plurality of first

15   active antenna elements having polarization diversity from said plurality of second active

antenna elements;

a first transform matrix, coupled to said multi-columnar antenna

arrangement, for forming a plurality of narrow beam patterns that span different angular

directions in a predetermined plane, said first transform matrix being associated with said

20   plurality of first active antenna elements and having a plurality of beam ports coupled to a

plurality of adjustment elements for adjusting a first plurality of beam port signals;

a second transform matrix, coupled to said multi-columnar antenna arrangement, for forming a plurality of narrow beam patterns that span different angular directions in a predetermined plane, said second transform matrix being associated with said plurality of second active antenna elements and having a plurality of beam ports

5   coupled to a plurality of adjustment elements for adjusting a second plurality of beam port signals;

a combined signal splitter for splitting a combined signal into a first split signal and a second split signal;

a delay unit for delaying said first split signal;

10   a first splitter for splitting said delayed first split signal into a first plurality of beam port signals; and

a second splitter for splitting said second split signal into a second plurality of beam port signals, ·

wherein said first and second plurality of beam port signals are adjusted and

15   supplied to said first transform matrix and said second transform matrix, respectively.

14.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of first active antenna elements and a plurality of second active antenna elements, said plurality of first

20   active antenna elements having polarization diversity from said plurality of second active antenna elements;

a first set of adjustment elements coupled to each of said plurality of first

active antenna elements for adjusting radiation characteristics of said first active antenna

elements;

a second set of adjustment elements coupled to each of said plurality of

5   second active antenna elements for adjusting radiation characteristics of said second active

antenna elements;

a transform matrix for forming a plurality of narrow beam patterns that span

different angular directions in a predetermined plane, said transform matrix having a

plurality of beam ports and a plurality of antenna ports.

10

15.   The method of Claim 14, wherein said plurality of first active antenna

elements and said plurality of second active antenna elements are transmit antenna

elements, said transform matrix processes signals to be transmitted by said first and second

active transmit antenna elements.

15

16.   A base station antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of first active

antenna elements and a plurality of second active antenna elements, said plurality of first

active antenna elements having polarization diversity from said plurality of second active

20   antenna elements;

a first transform matrix, coupled to said multi-columnar antenna

arrangement, for forming a plurality of narrow beam patterns that span different angular

directions in a predetermined plane, said first transform matrix being associated with said

plurality of first active antenna elements and having a plurality of beam ports coupled to a

plurality of first transform adjustment elements for adjusting a first plurality of beam port

signals;

5   a second transform matrix, coupled to said multi-columnar antenna

arrangement, for forming a plurality of narrow beam patterns that span different angular

directions in a predetermined plane, said second transform matrix being associated with

said plurality of second active antenna elements and having a plurality of beam ports

coupled to a plurality of second transform adjustment elements for adjusting a second

10   plurality of beam port signals;

a signal splitter for splitting a combined signal into a first split signal and a

second split signal;

a first set of adjustment elements for adjusting said first split signal;

a second set of adjustment elements for adjusting said second split signal;

15   a first splitter for splitting said adjusted first split signal into a first plurality

of beam port signals;   and

a second splitter for splitting said adjusted second split signal into a second

plurality of beam port signals,

wherein said first and second plurality of beam port signals are further

20   respectively adjusted by said first and second transform adjustment elements and then

respectively supplied to said first transform matrix and said second transform matrix.

17.   A base station multi-carrier antenna system comprising:

a multi-columnar antenna arrangement containing a plurality of active antenna elements;

a transform matrix, coupled to said multi-columnar antenna arrangement,
5   for forming a plurality of narrow beam patterns that span different angular directions in a predetermined plane, said transform matrix having a plurality of beam ports;

a plurality of frequency separators, coupled to said beam ports, for separating signals from said beam ports into a plurality of constituent carrier frequency signals,

10   a plurality of adjustment elements for adjusting each of said plurality of carrier frequency signals;

a plurality of combiners, wherein each of said plurality of combiners combines all adjusted carrier frequency signals of a predetermined frequency and outputs a predetermined frequency signal; and

15   a plurality of filters, wherein each of said plurality of filters is tuned to said predetermined frequency signal and is coupled to each of said combiners.
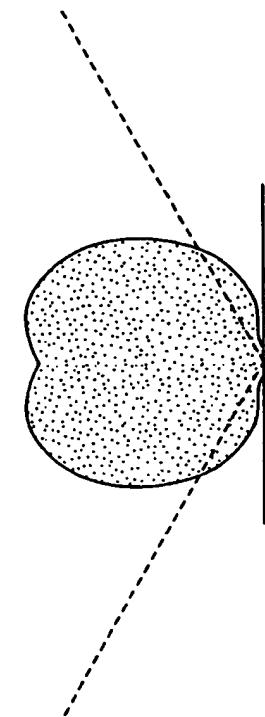
FIG. 1B
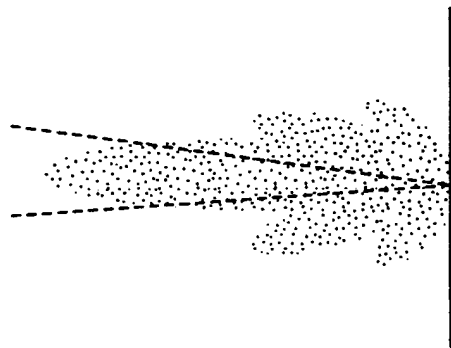
FIG. 1C
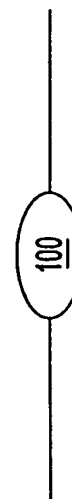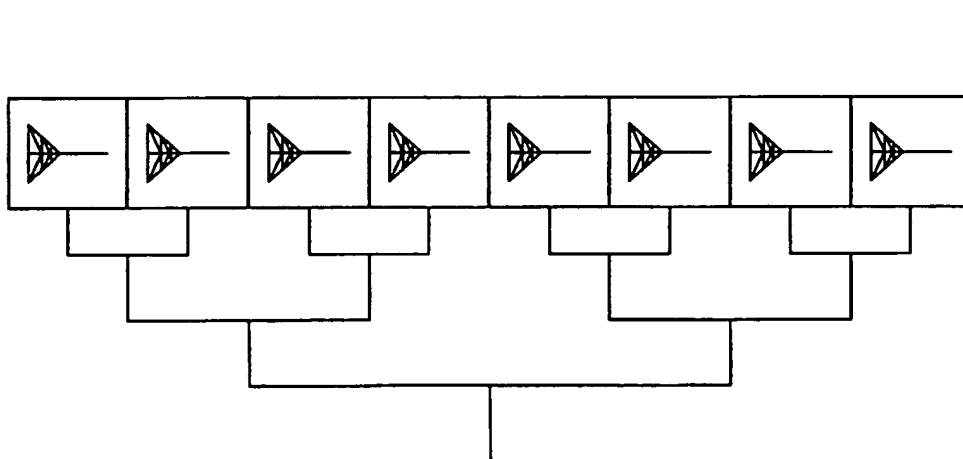
100

FIG. 1A

FIG. 2A

FIG. 2B

FIG. 3B

FIG. 3A

FIG.3C

FIG. 4

FIG. 5A

FIG. 5B

FIG. 6B

FIG. 7B

FIG. 6A

FIG. 7A
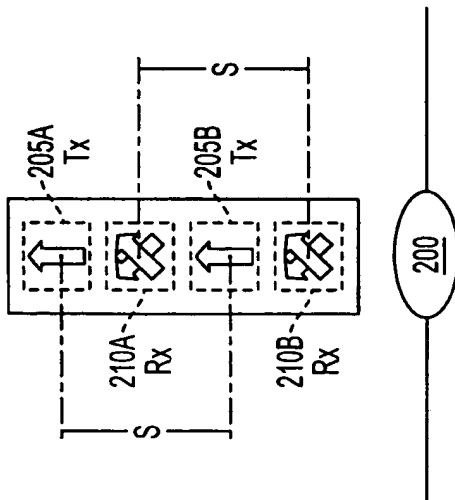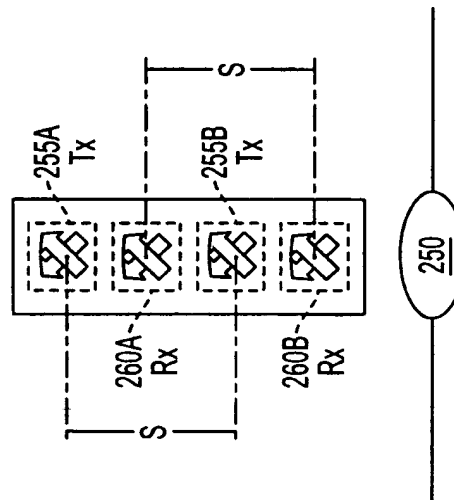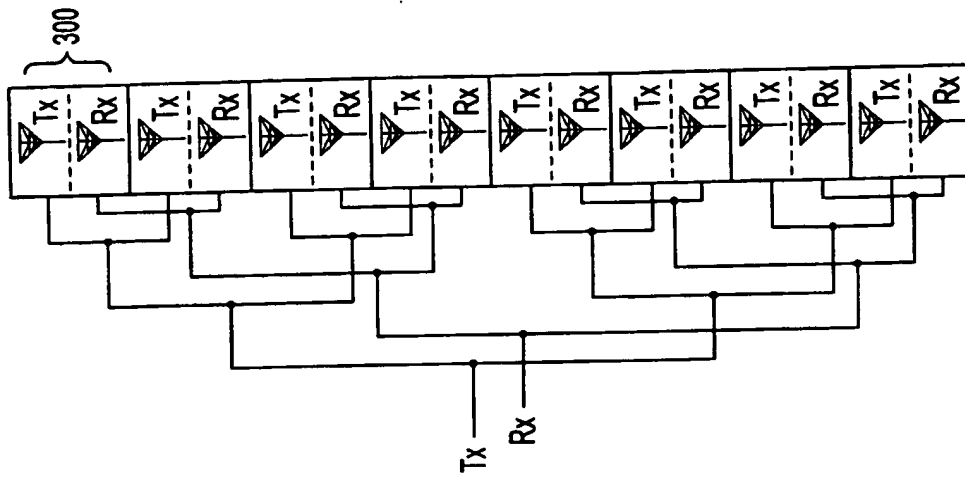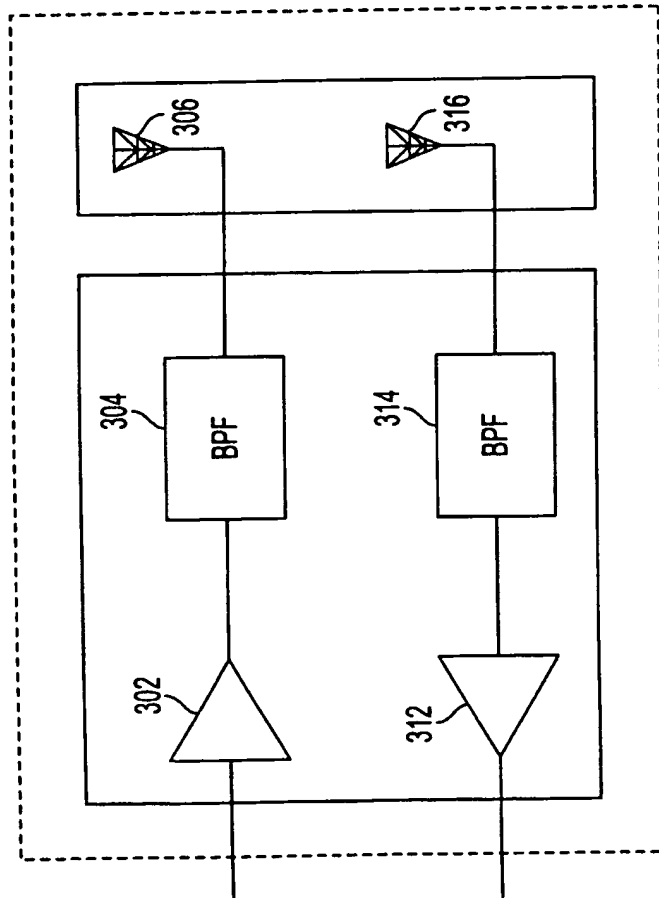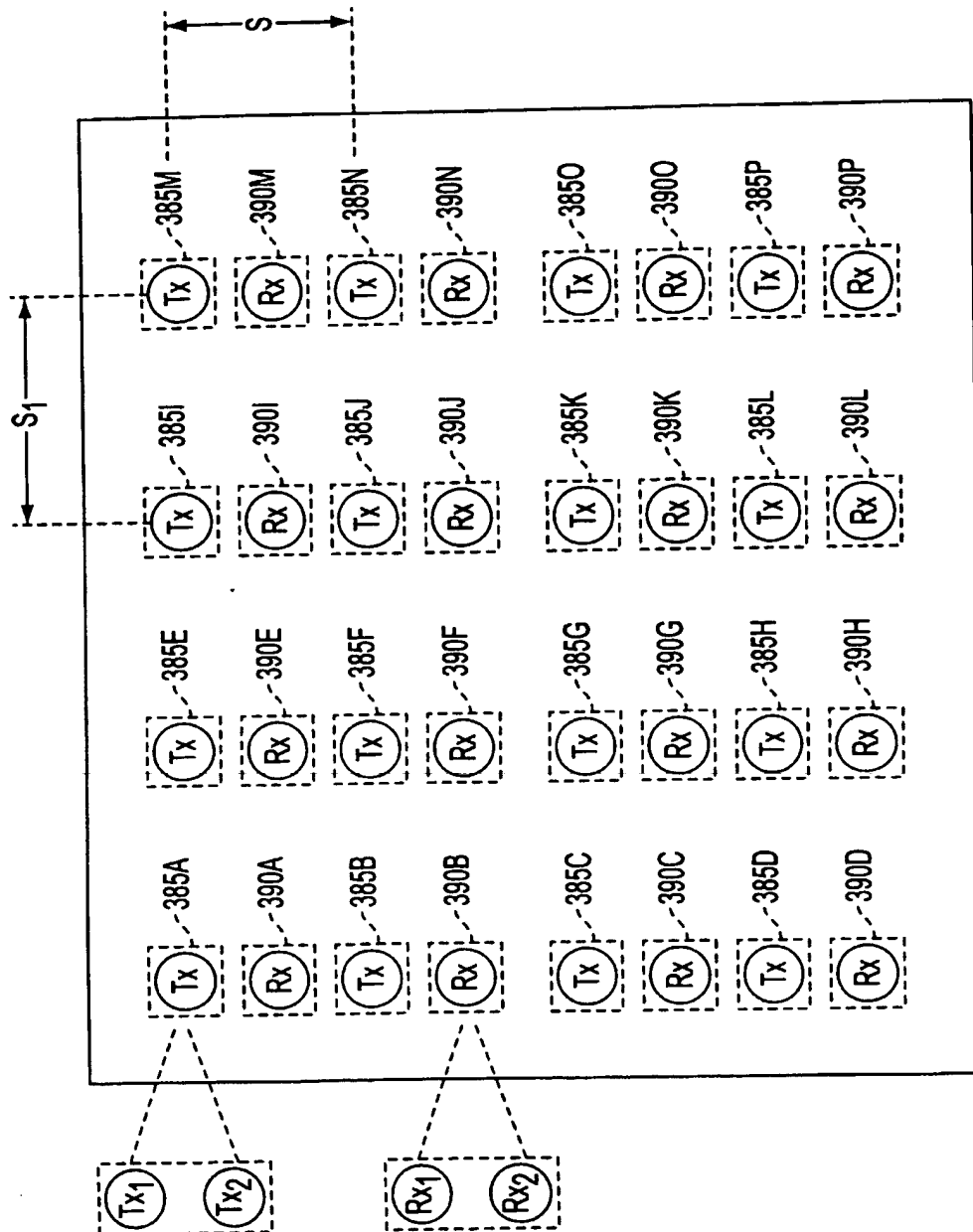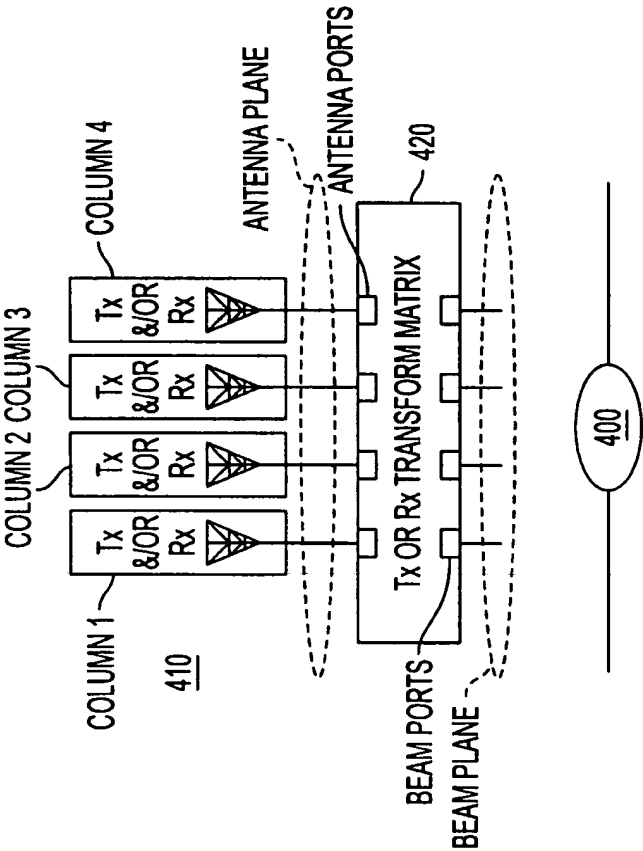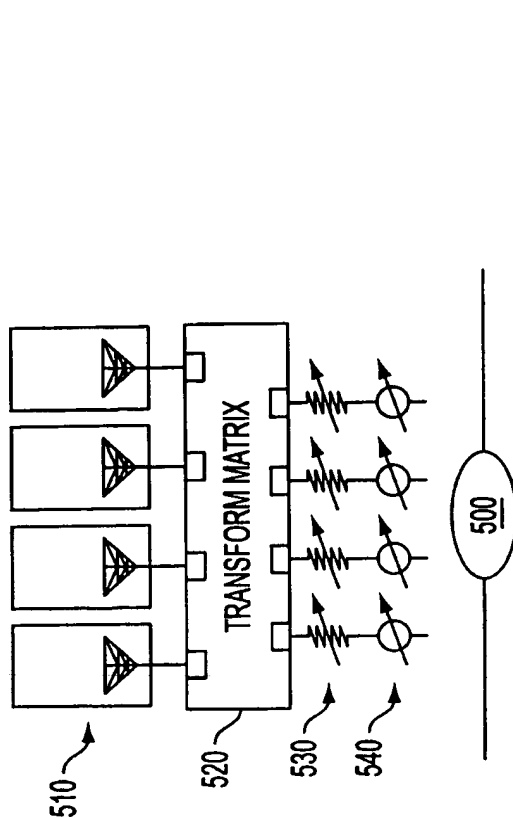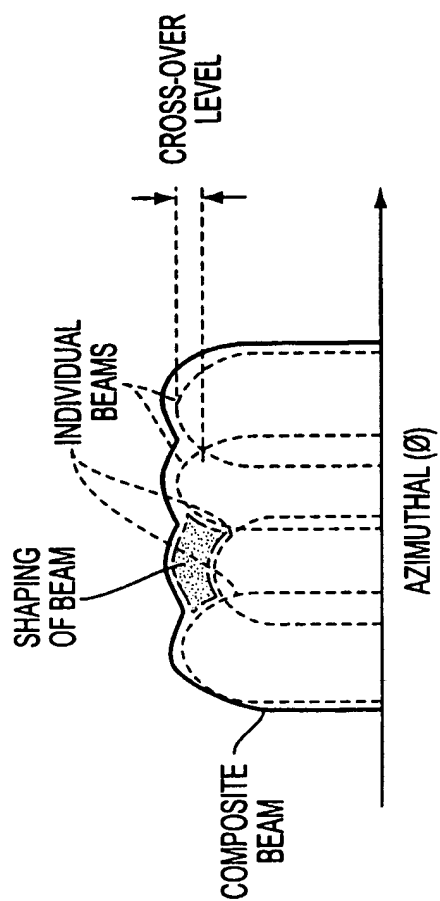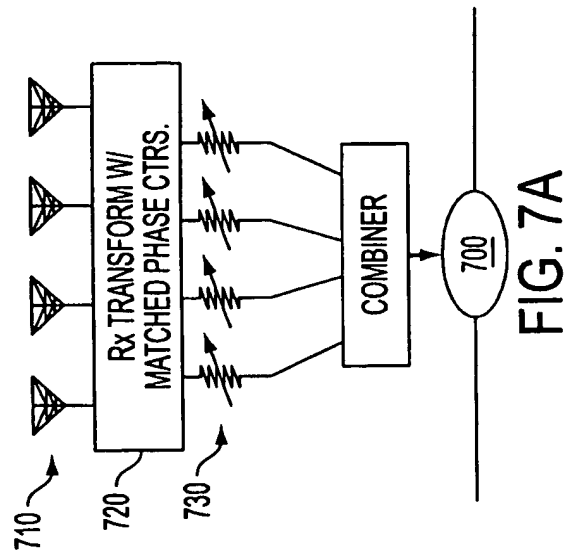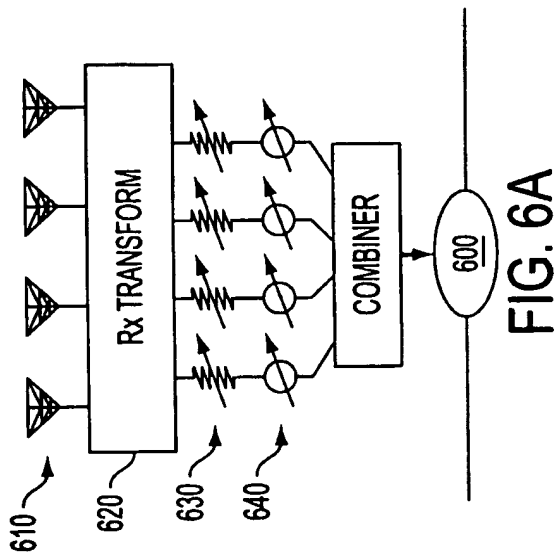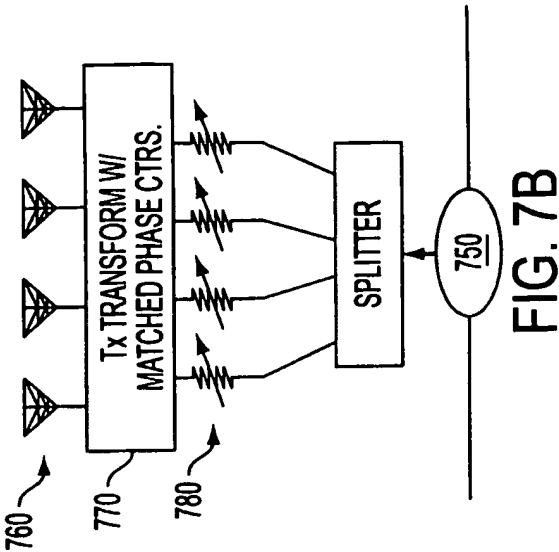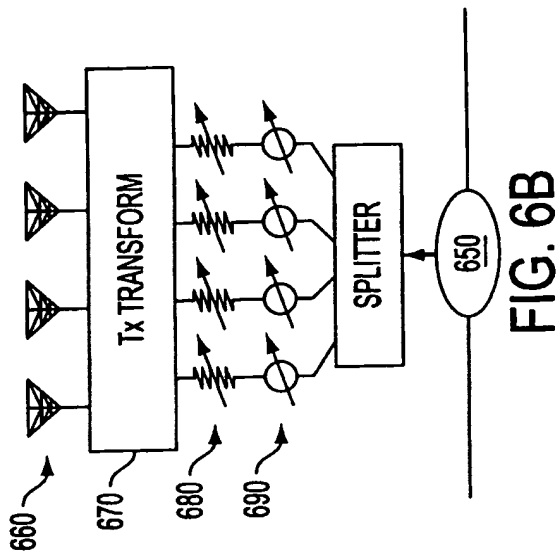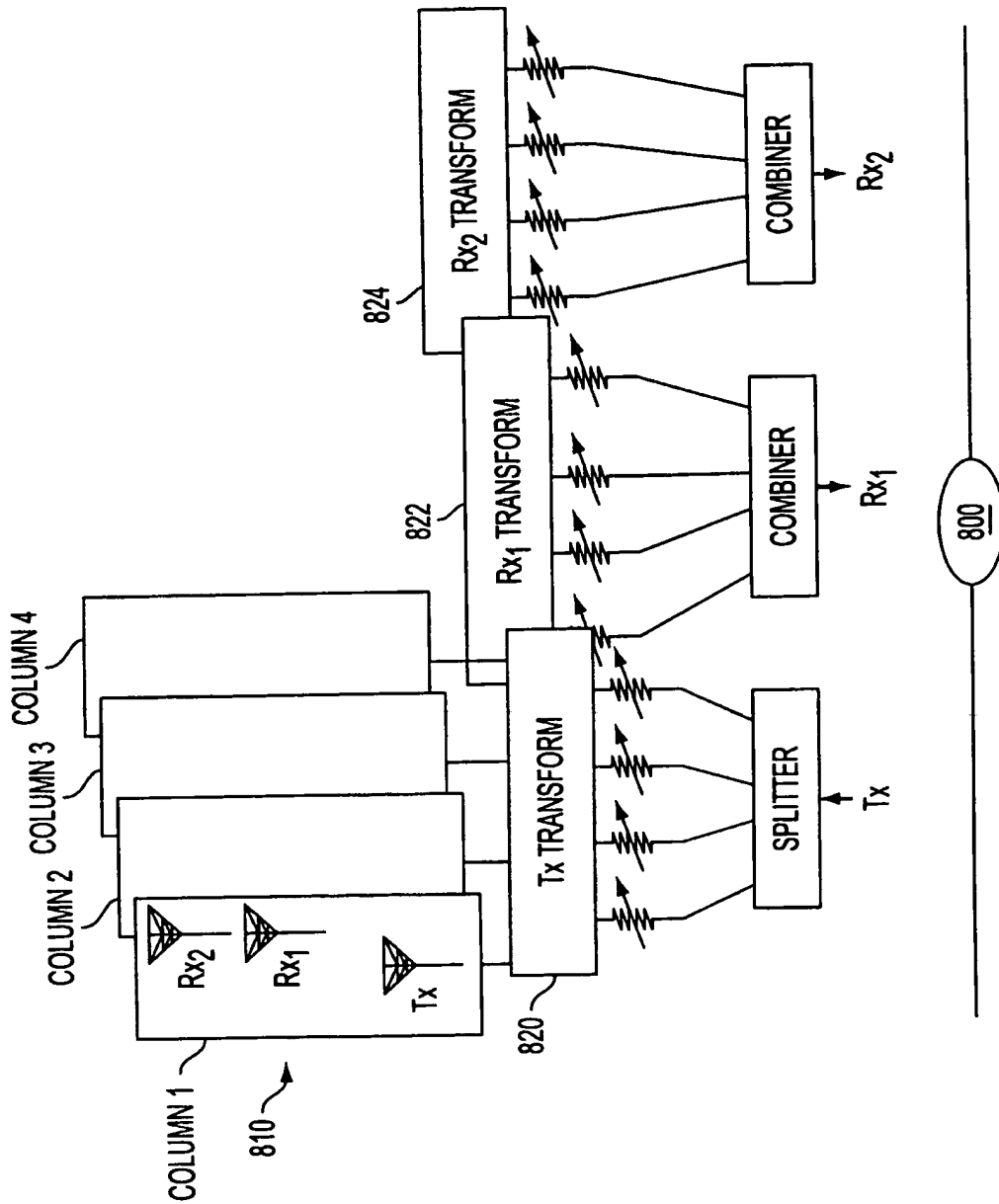
FIG. 8
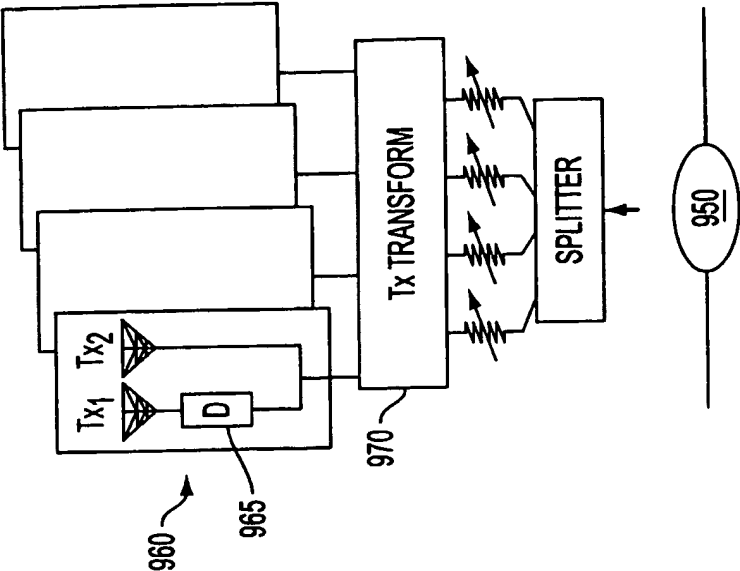
FIG. 9B

FIG. 9A

10/25
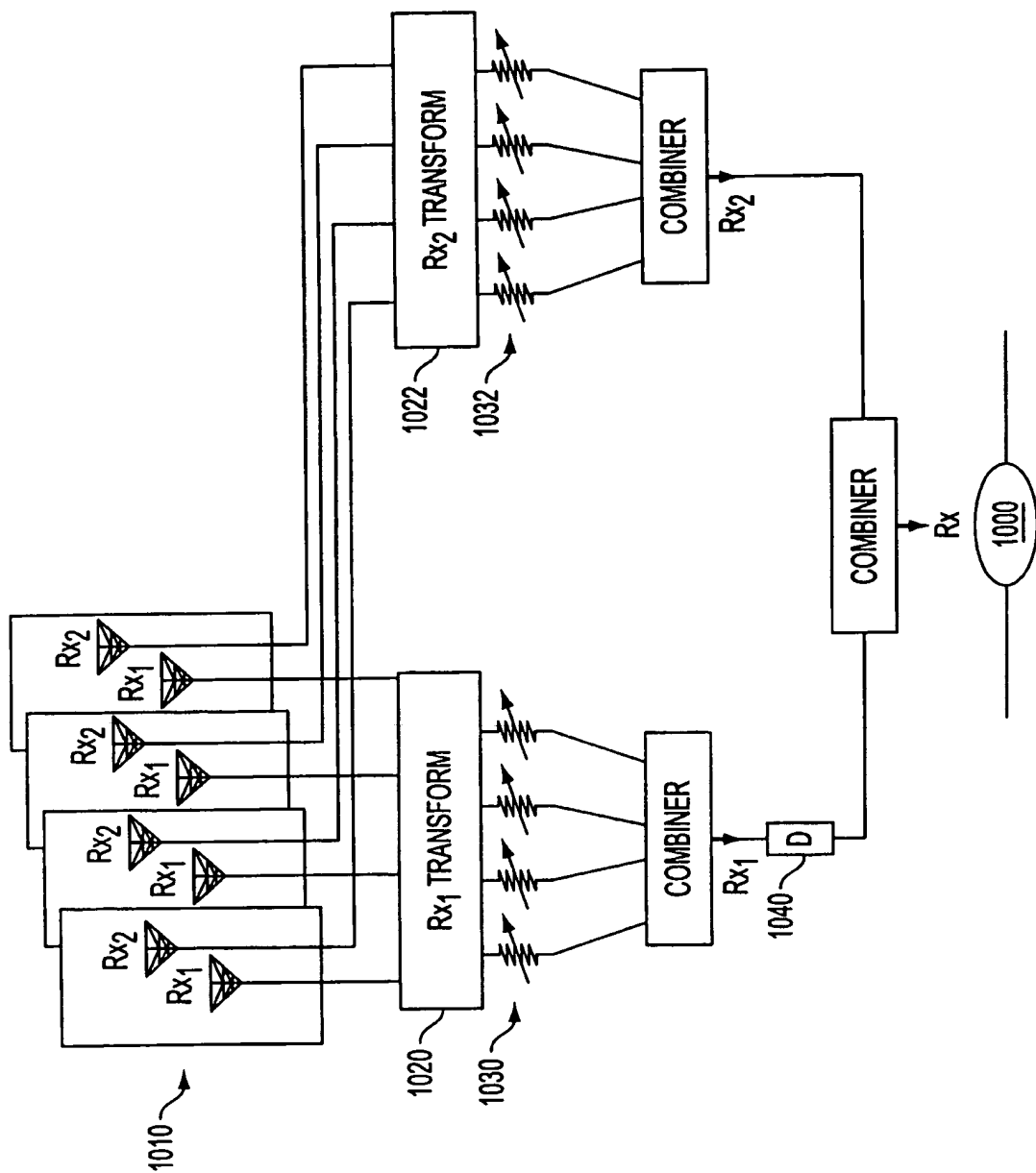
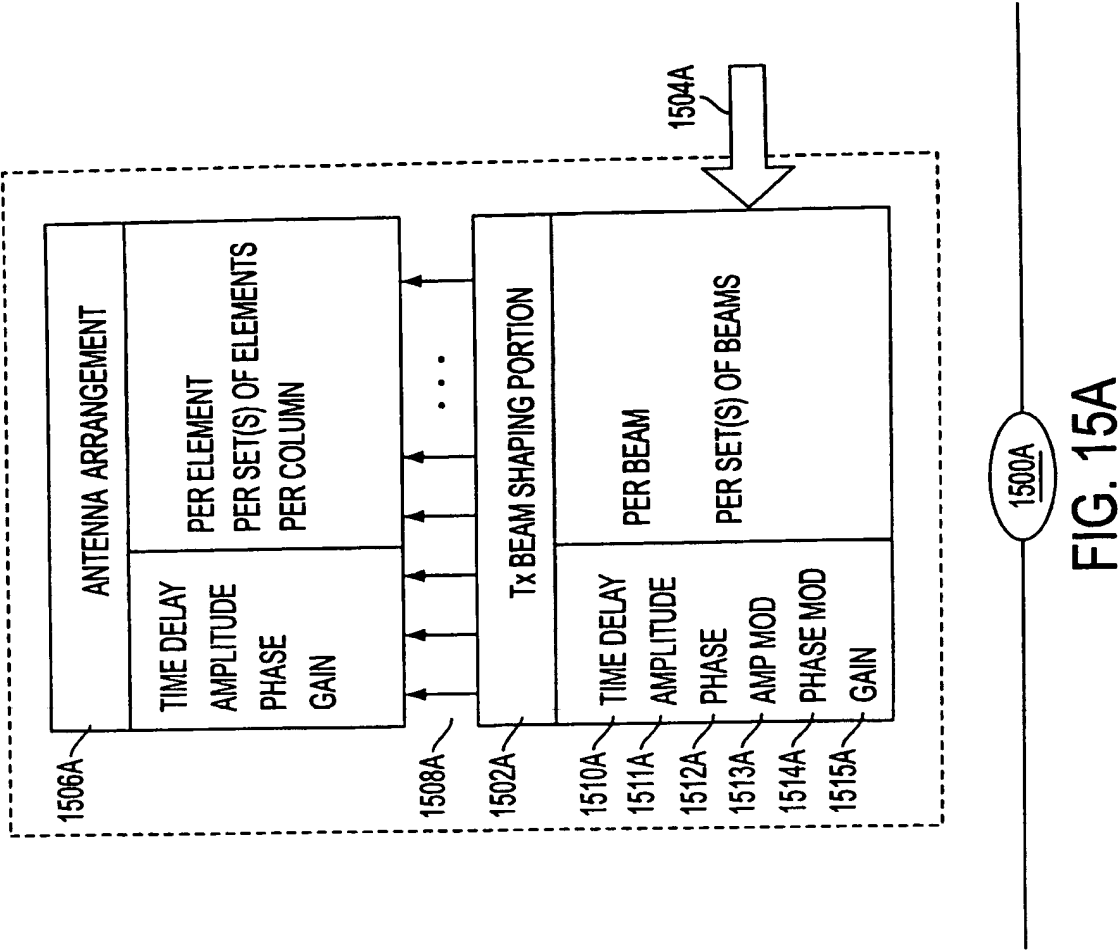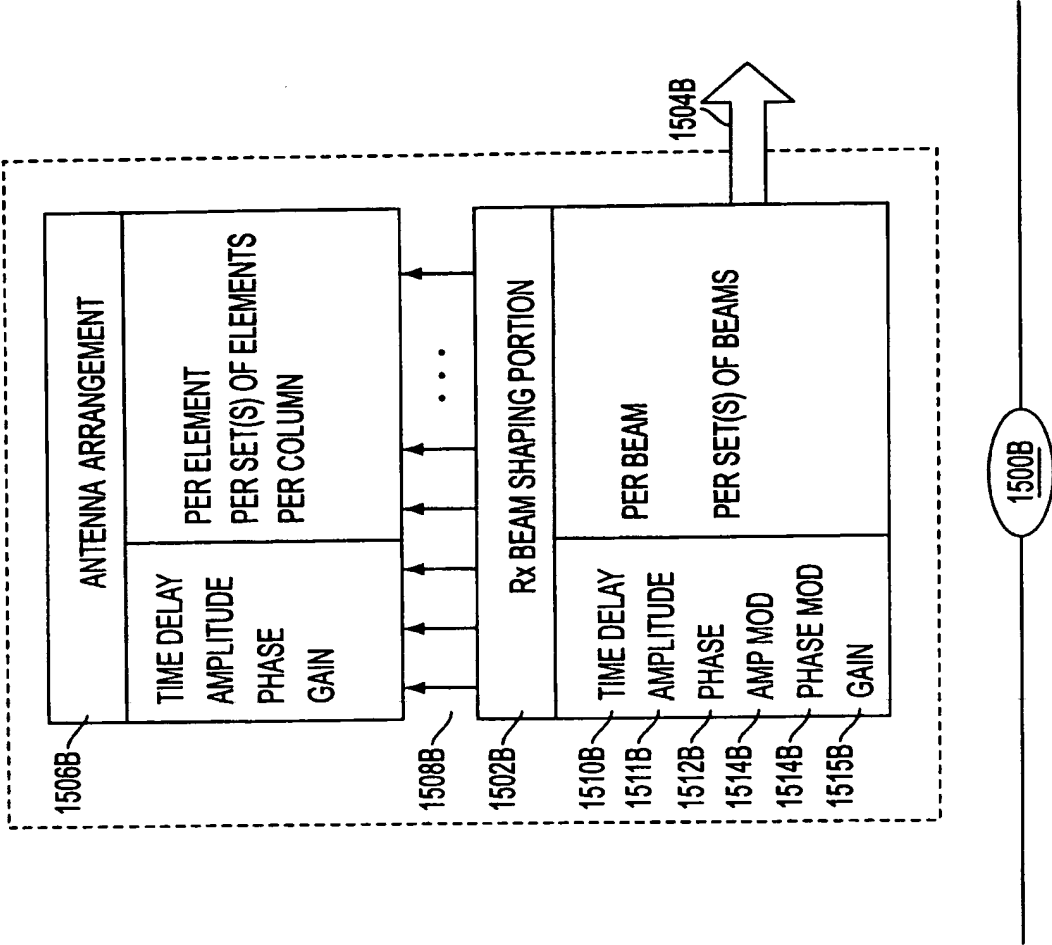
FIG. 10A
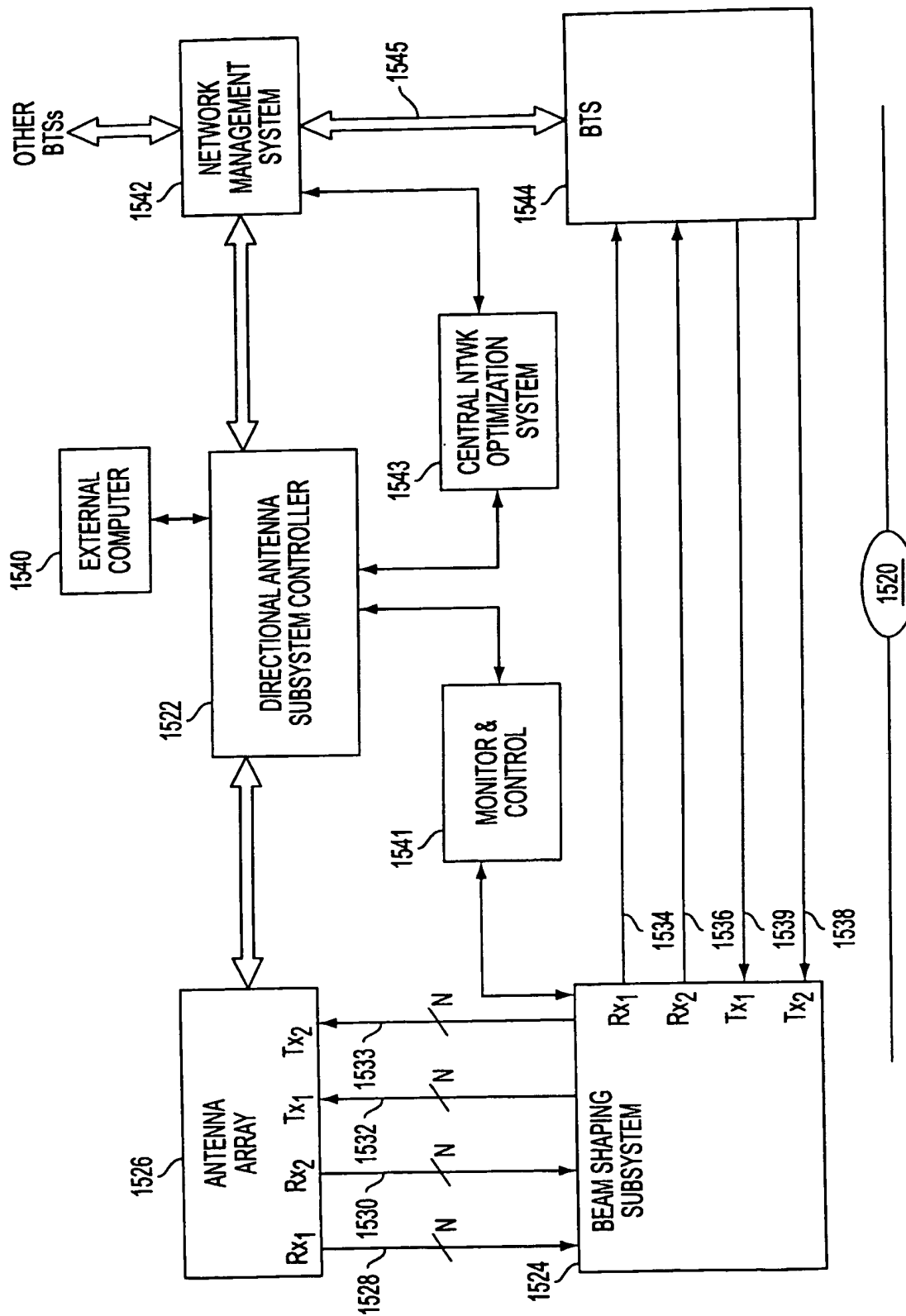
FIG. 10B

FIG. 11A

FIG. 11B

FIG. 12A

FIG. 12B

FIG. 13

17/25
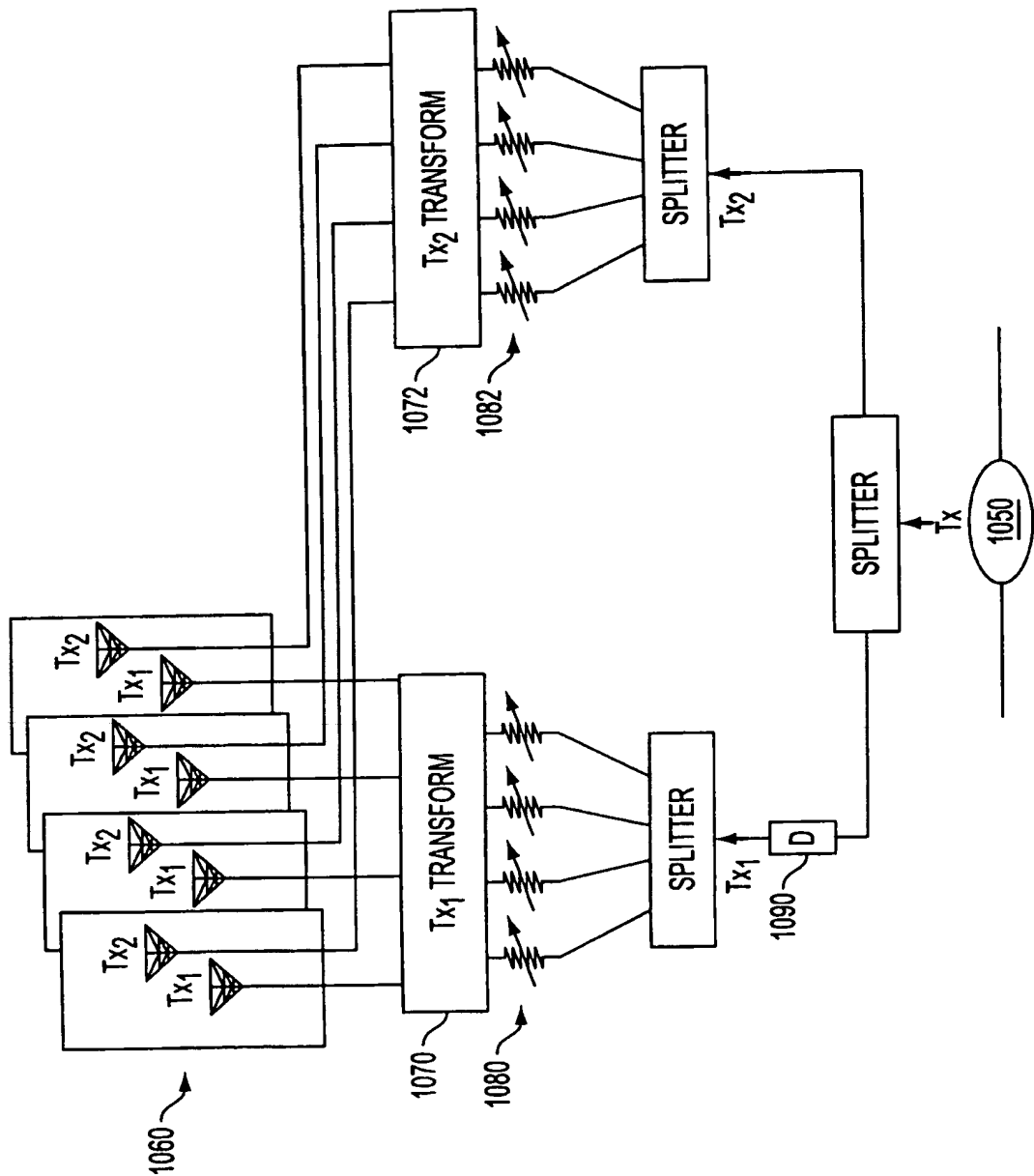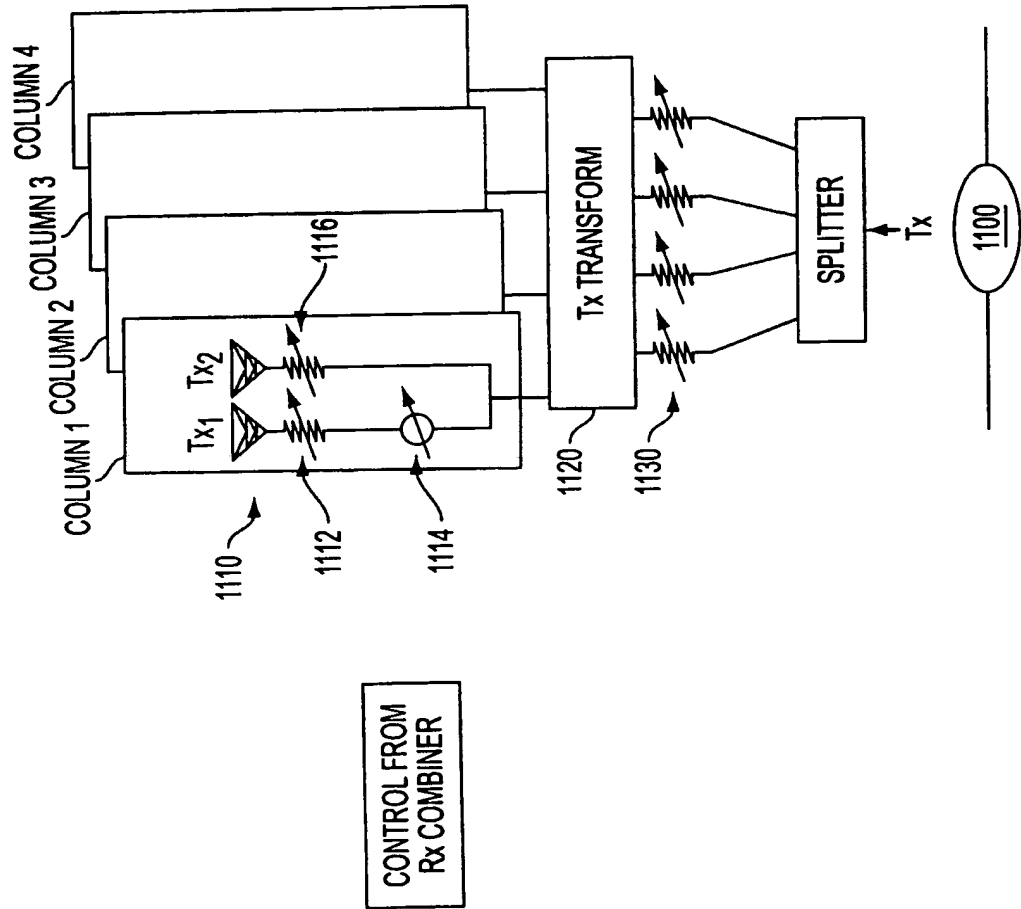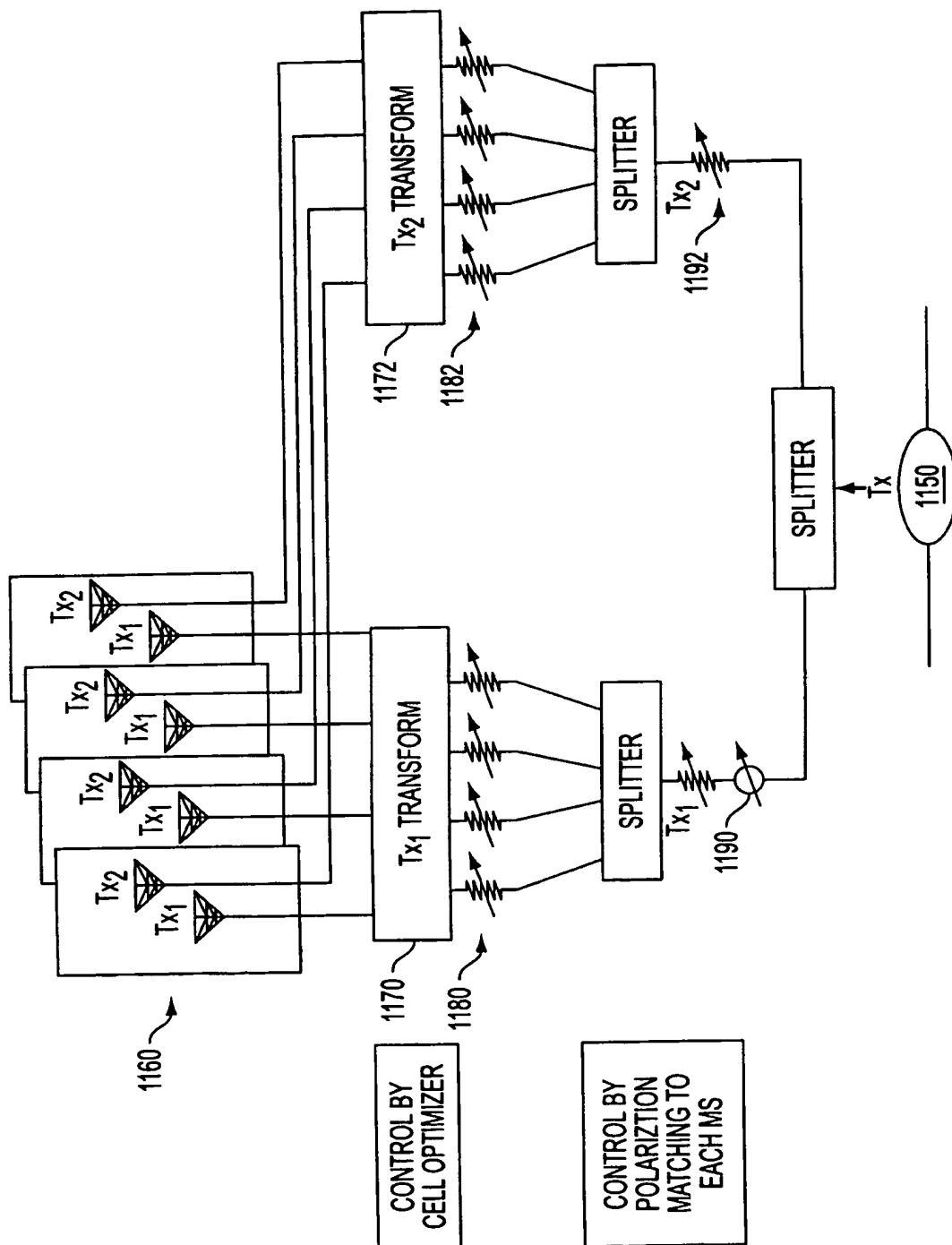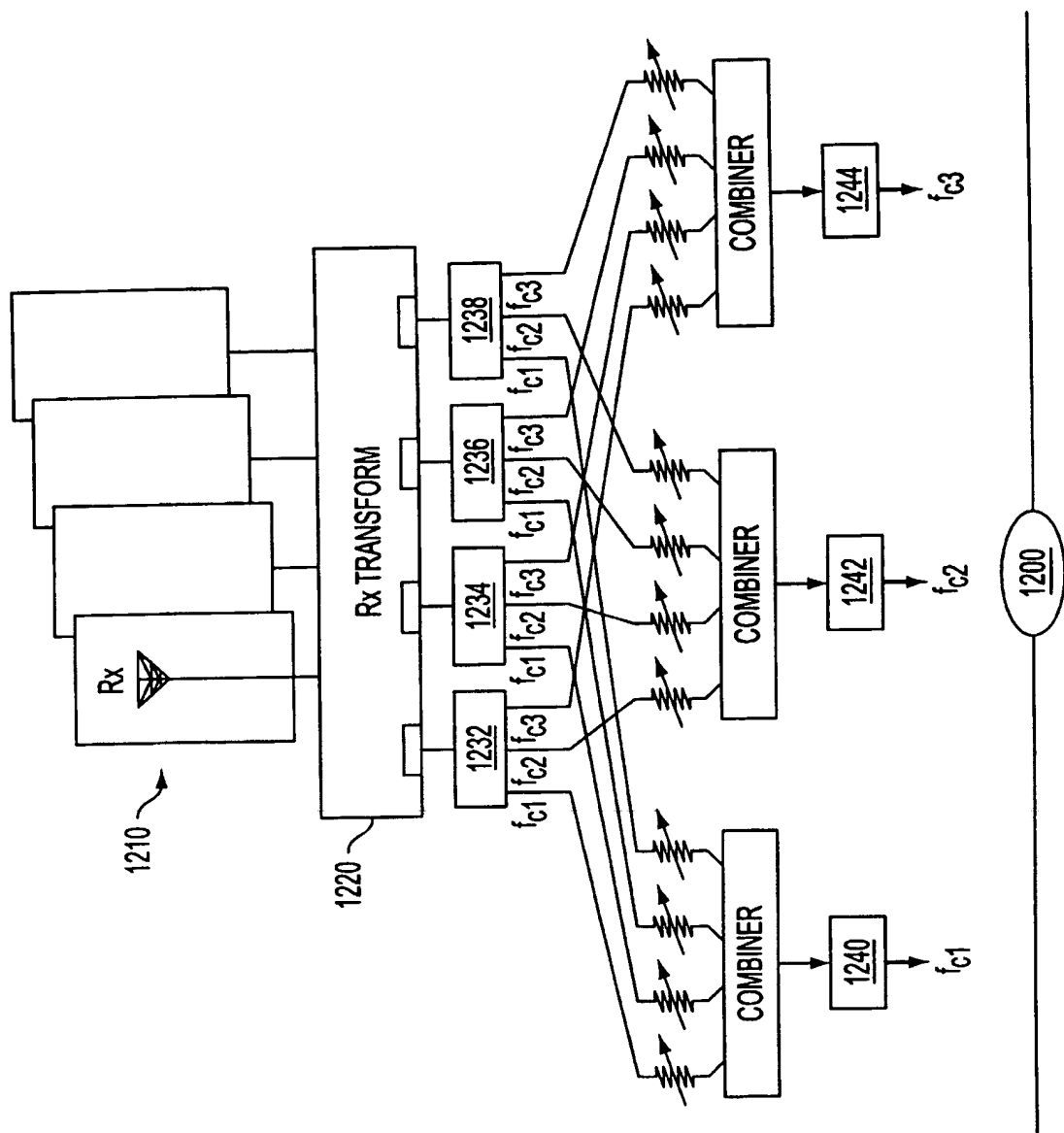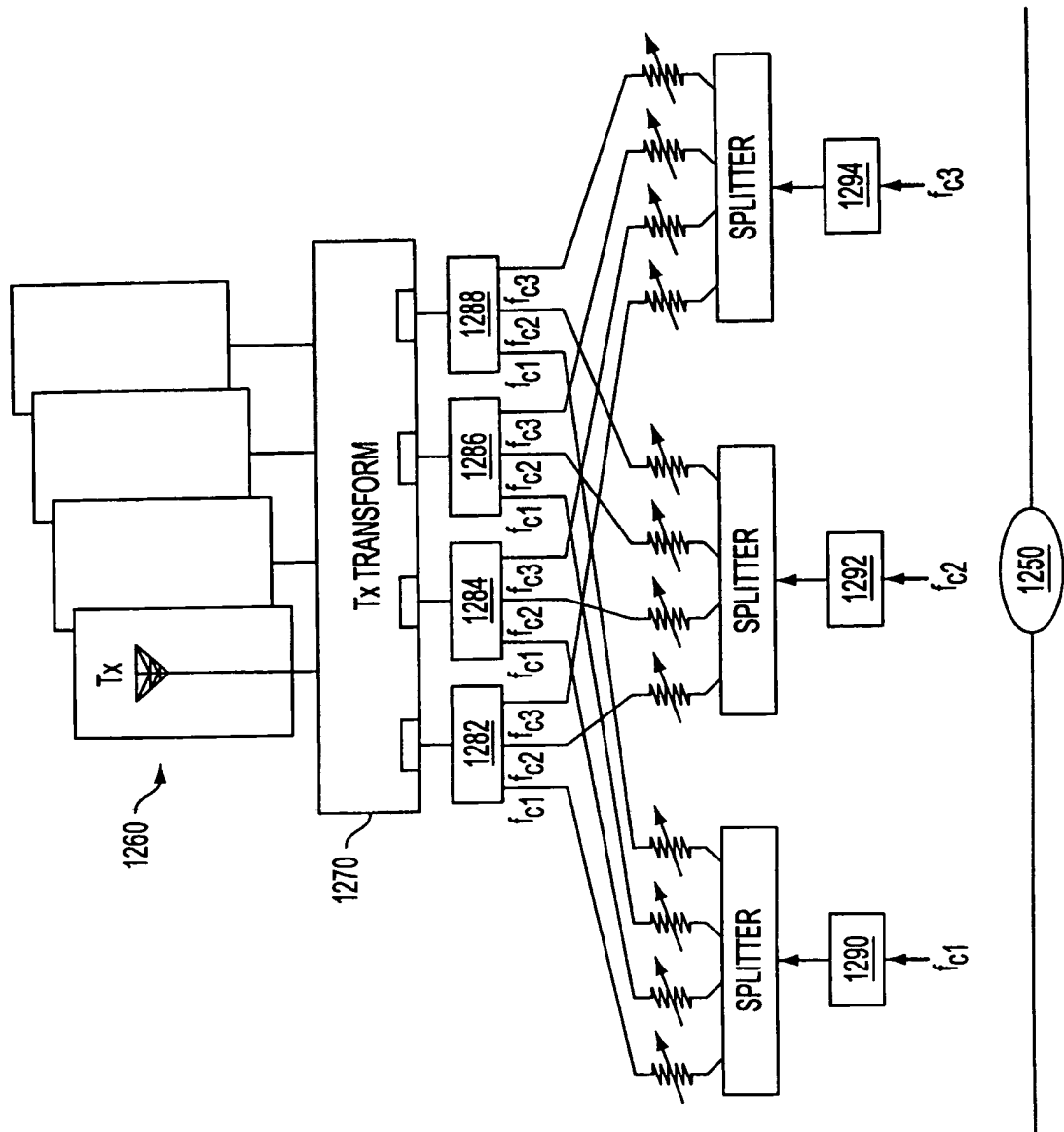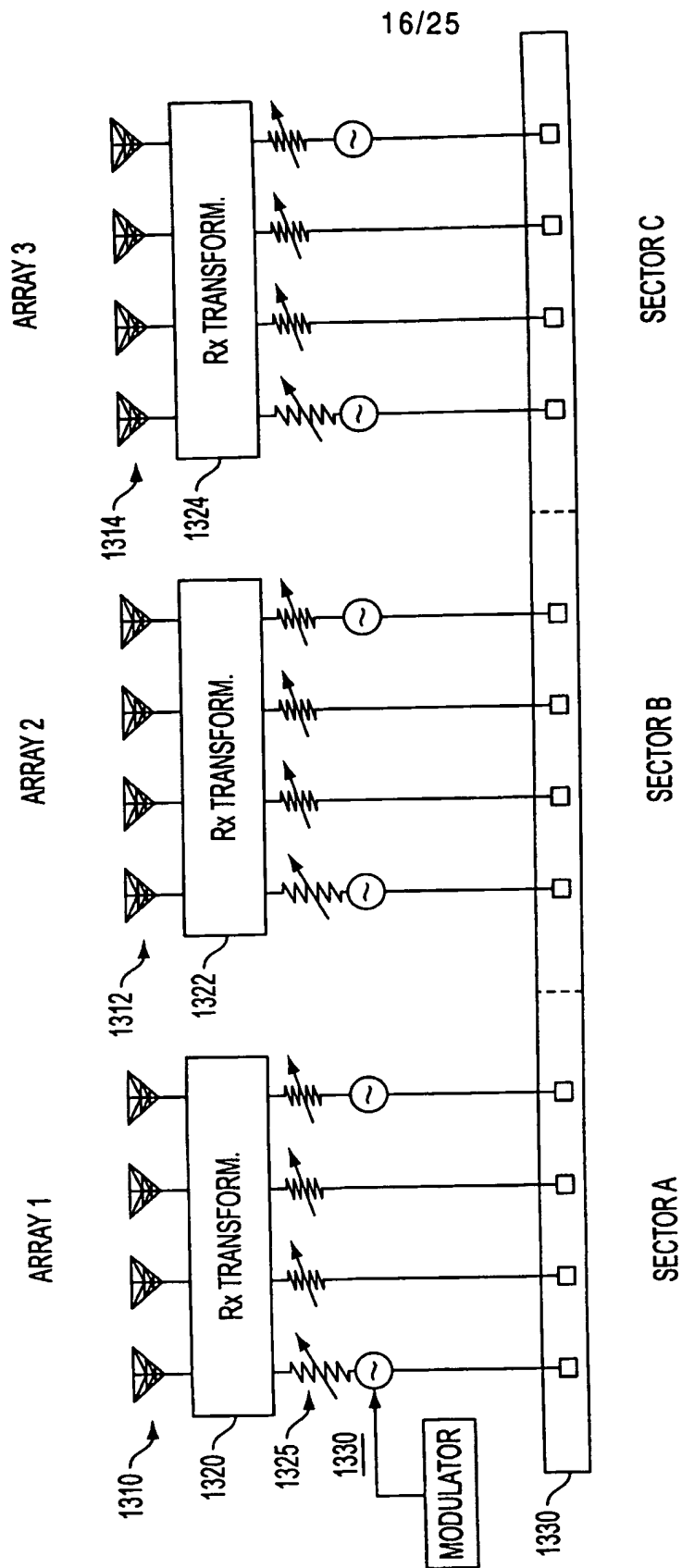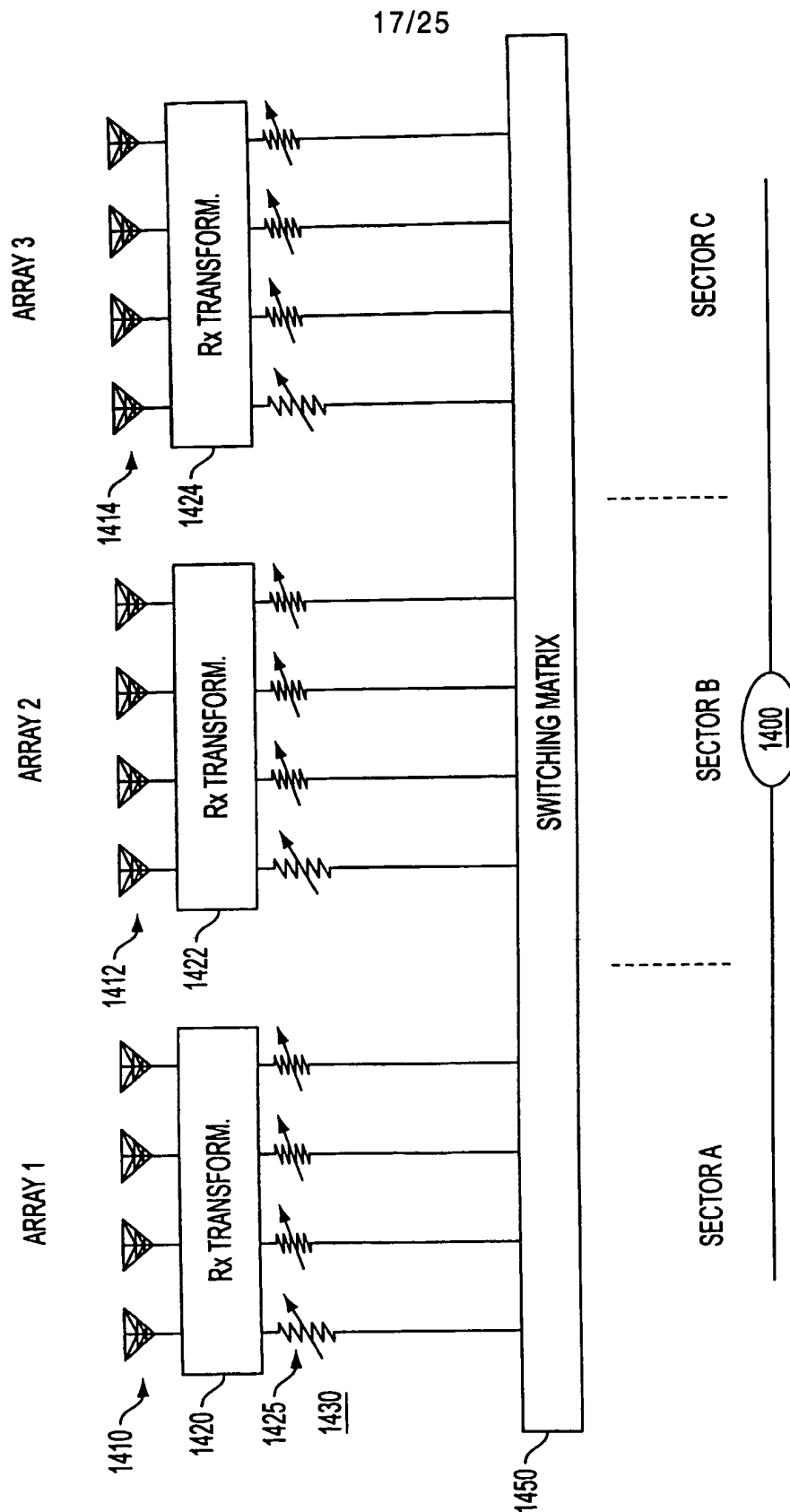
FIG. 14

FIG. 15A

FIG. 15B

FIG. 15C

FIG. 15D

FIG. 16

FIG. 17A

FIG. 17B

FIG. 18